Assessment of the Importance of Electron and Ion Kinetic Effects in Collisionless Plasmas

Homa Karimabadi

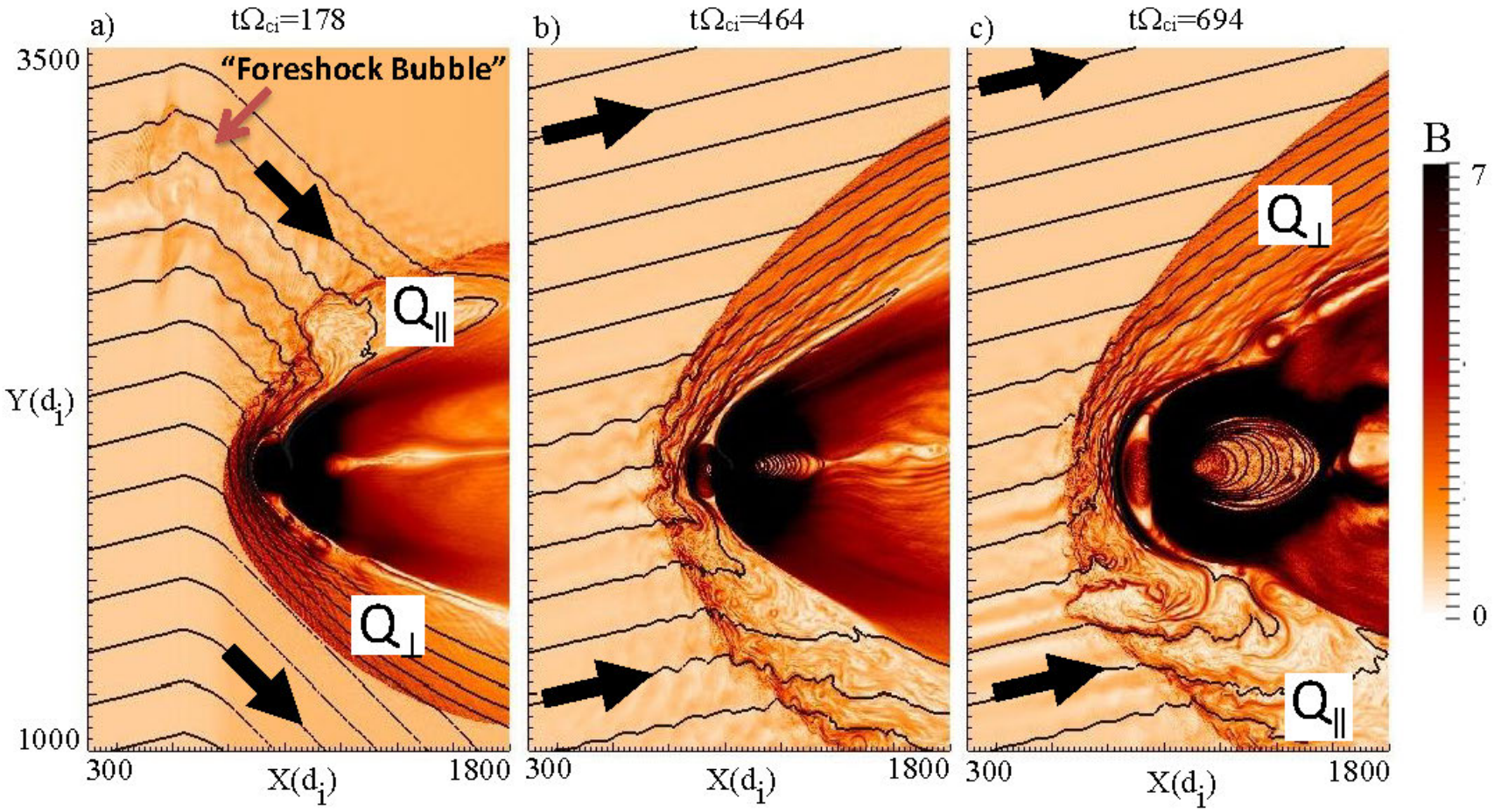
+ Many Great Collaborators

- 2D global hybrid vs 2D global full PIC vs global MHD
  - turbulence, reconnection, space weather effects
- 3D global hybrid vs 3D global MHD
  - space weather effects, 3D reconnection
- Full PIC simulations of magnetotail – onset problem
- 3D full PIC simulations of turbulence

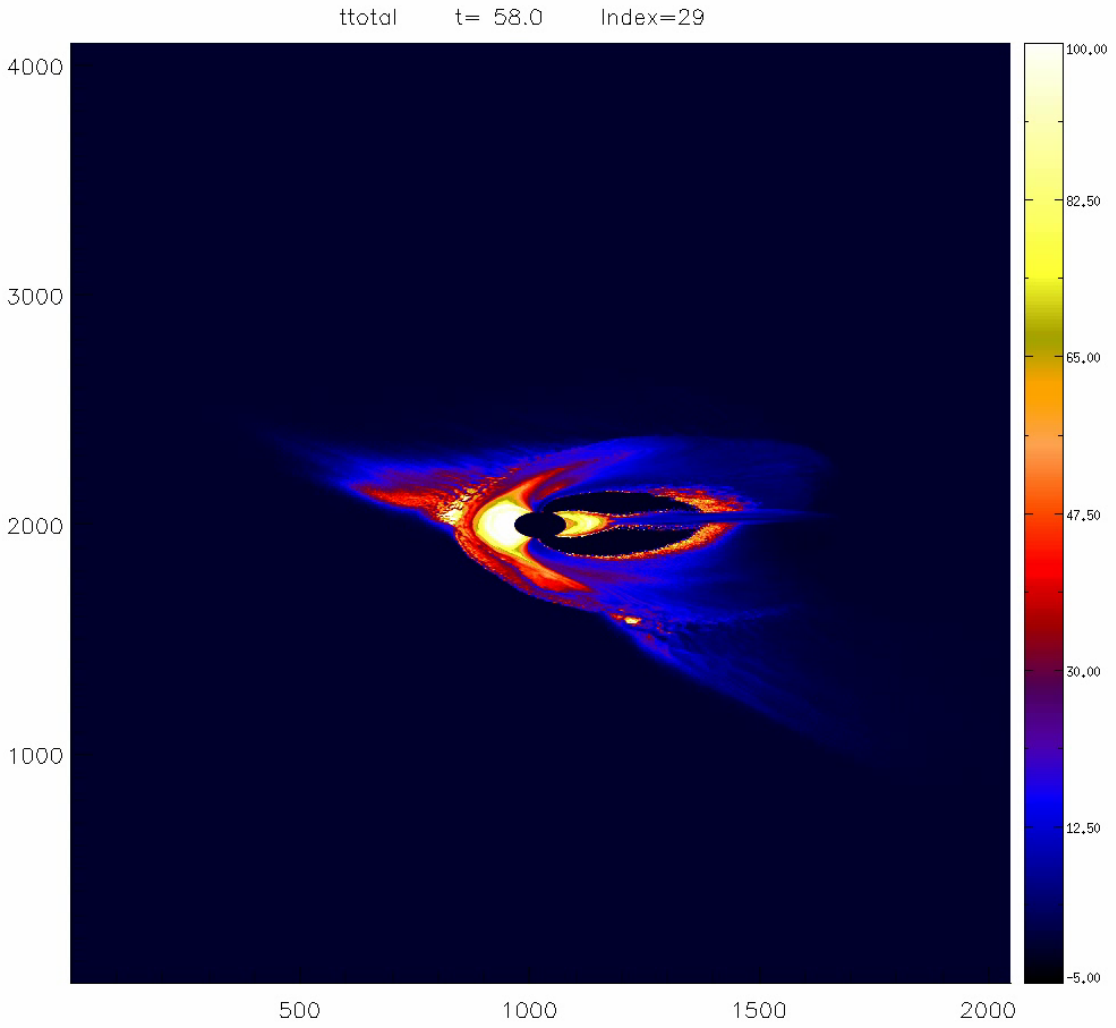
2D global hybrid

- Self-generation of ion scale turbulence has global consequences
  - formation of jets reaching the magnetopause
  - formation of large scale flow vortices
  - Generation of large scale wavefronts
  - Triggering of flux ropes at the magnetopause
  - Generation of anomalous flows

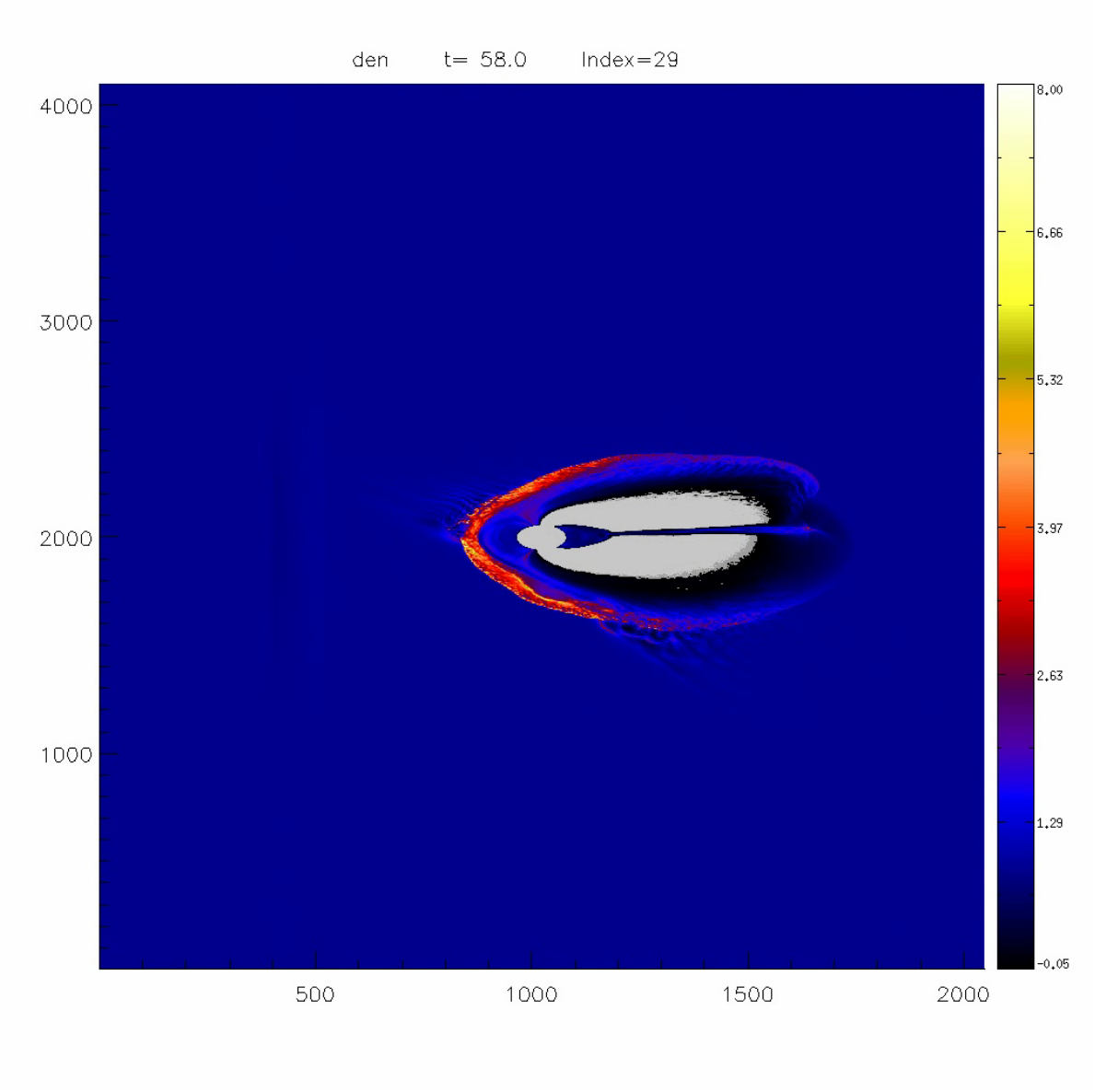
Changing IMF Direction in Time



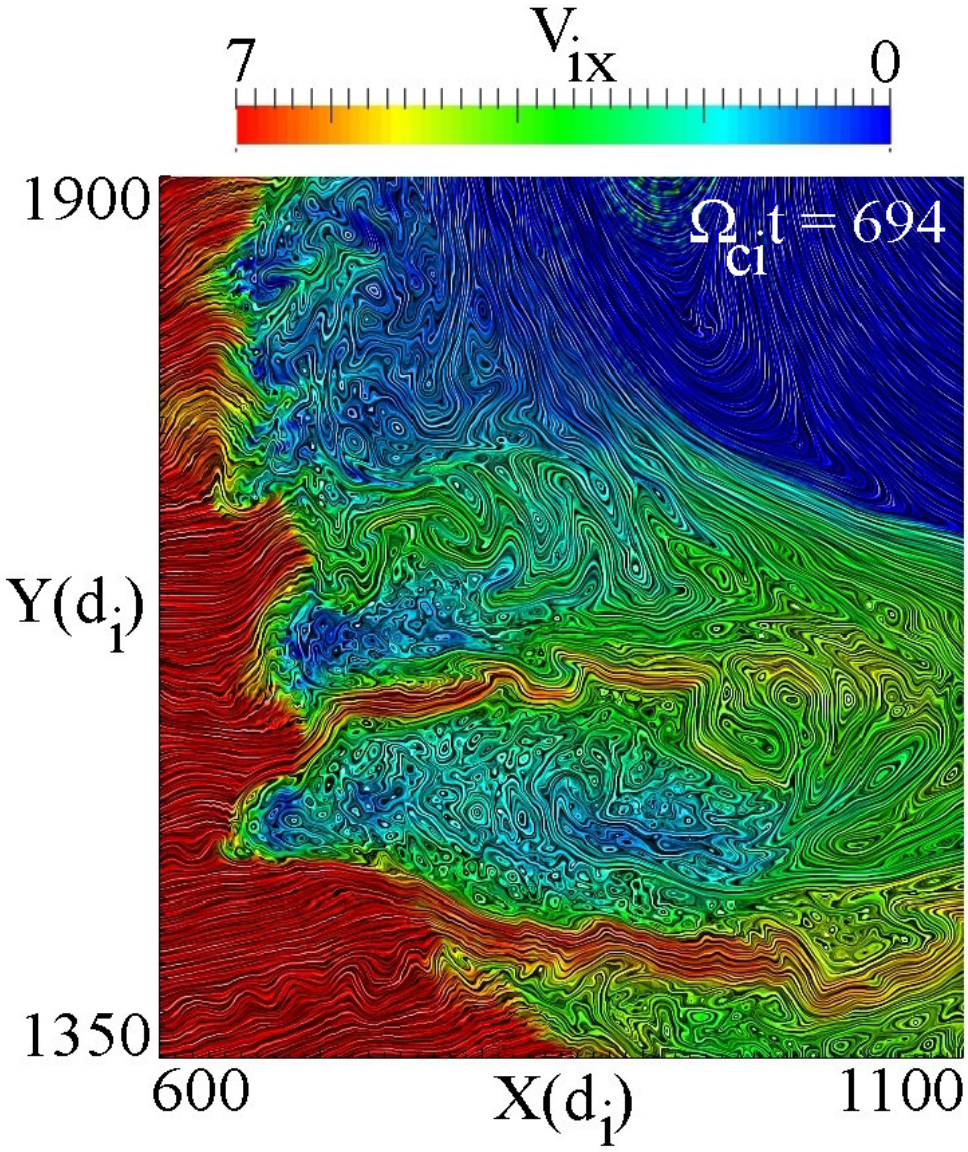
Self-generation of Turbulence



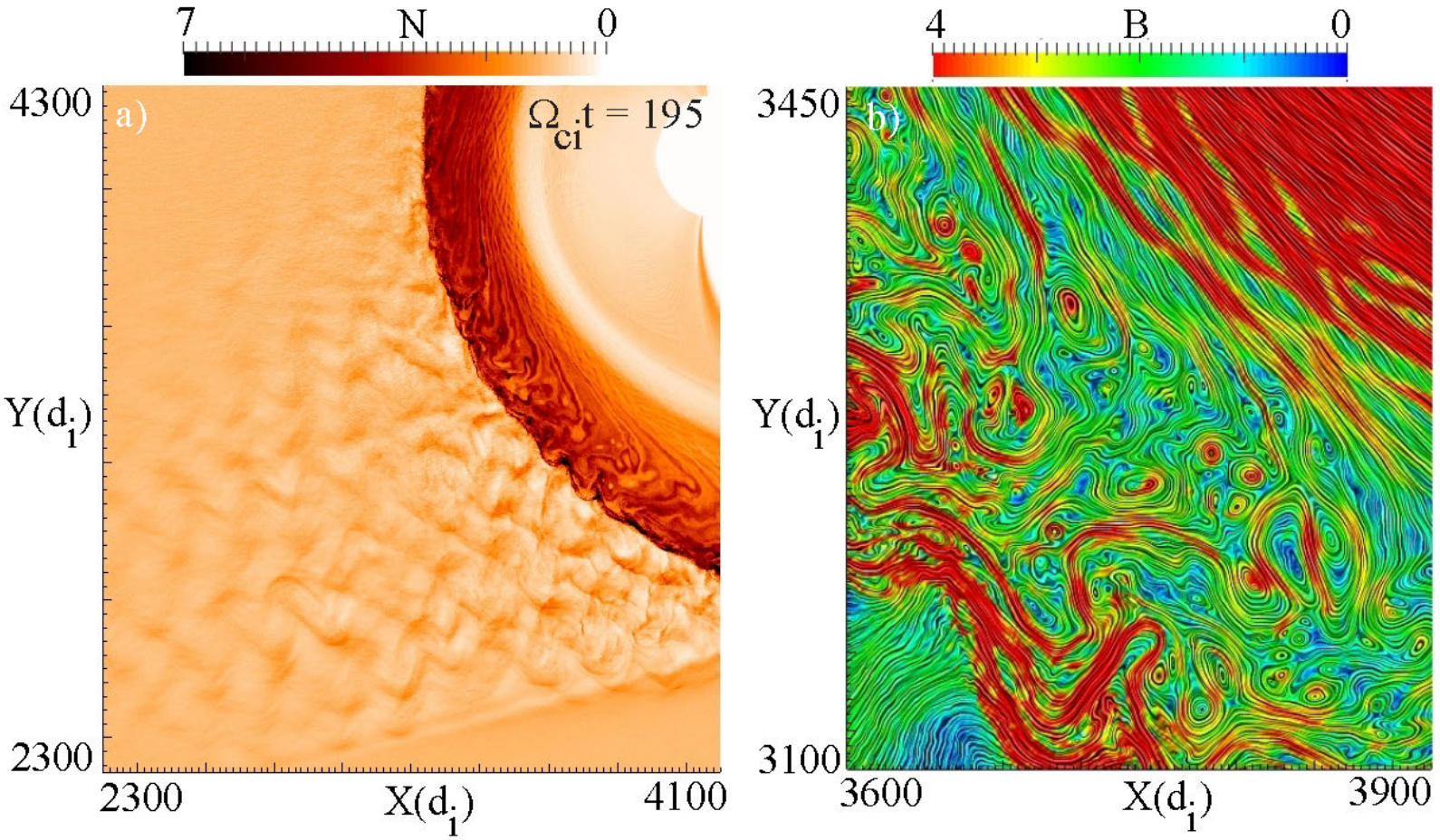
Self-generation of Turbulence



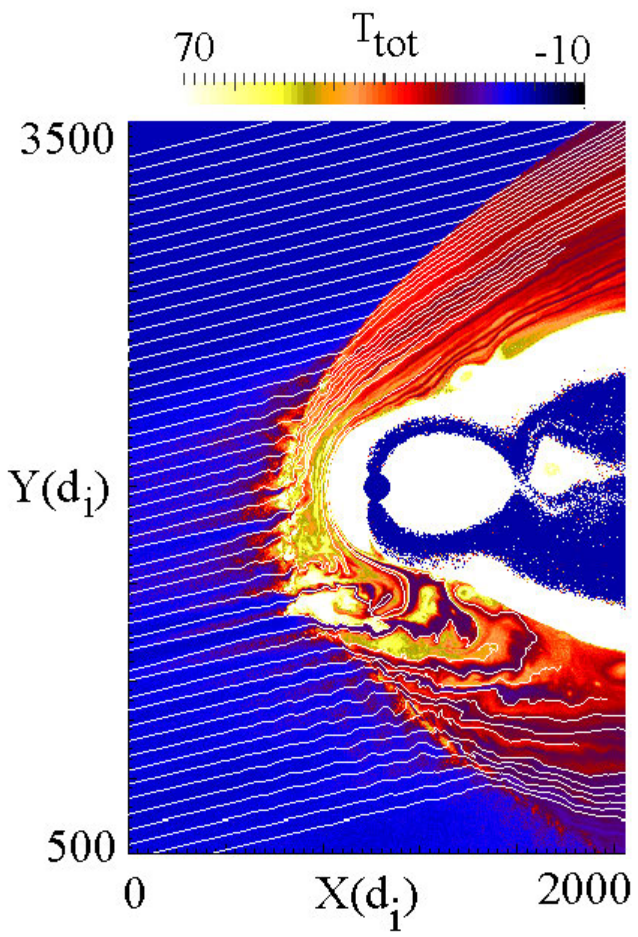
MicroReconnection/Turbulence

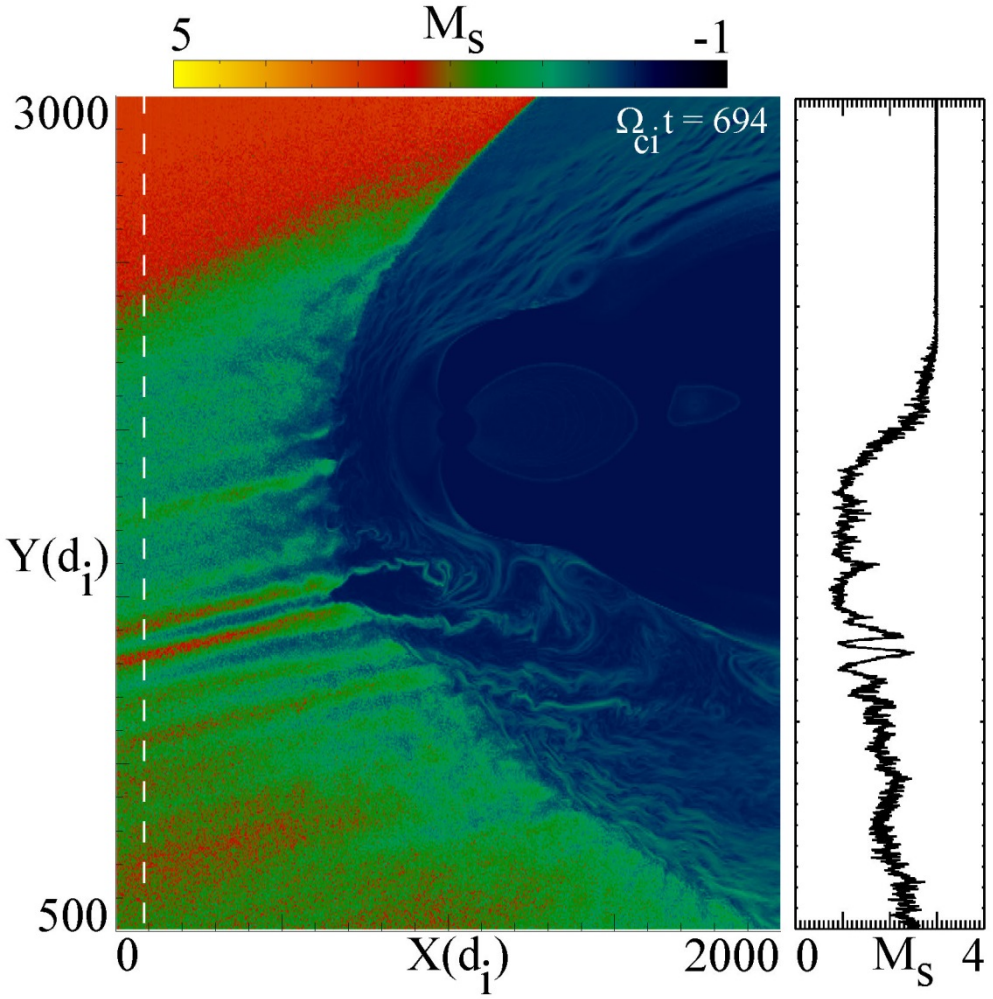


MicroReconnection/Turbulence

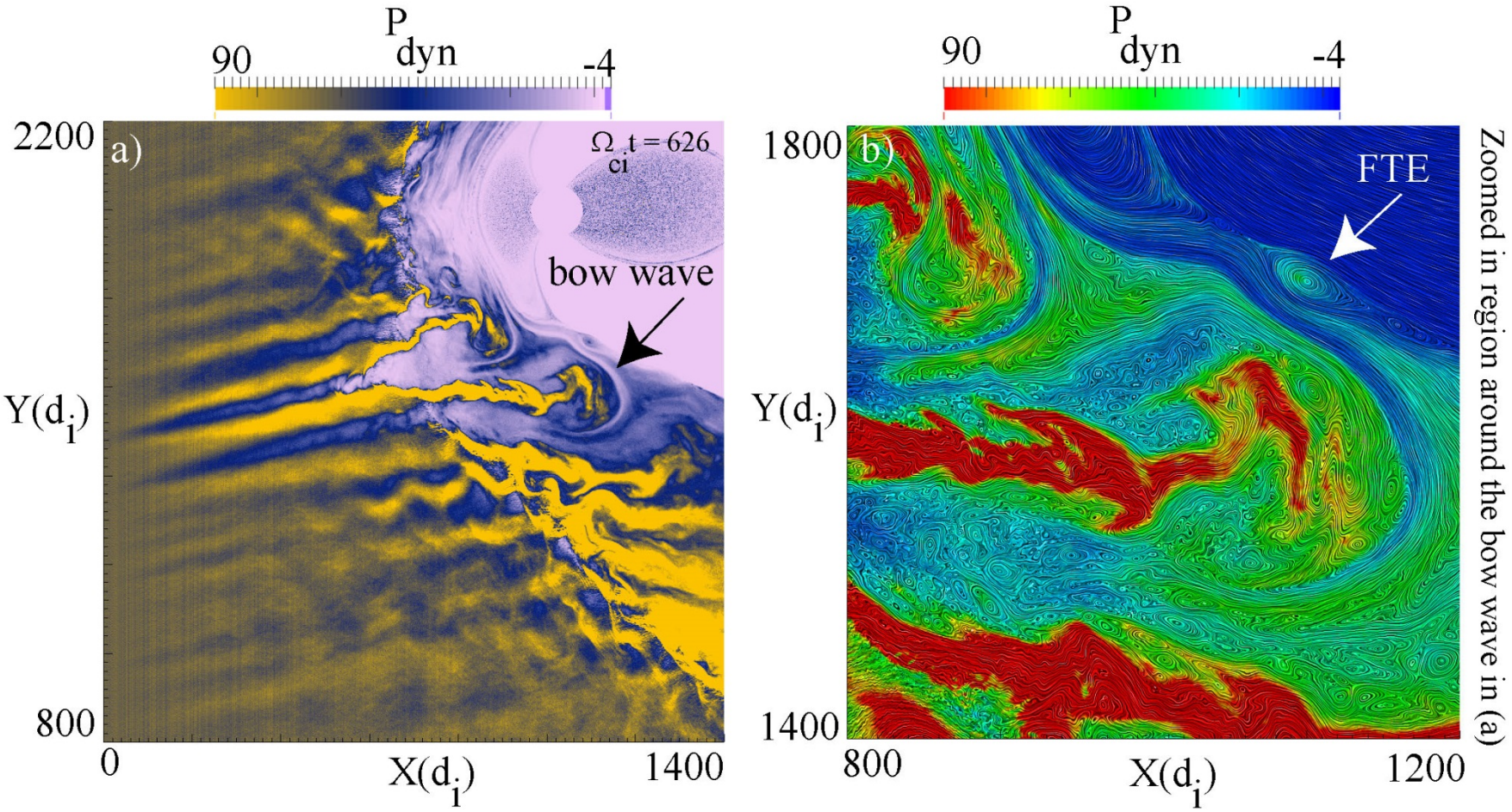


Unimpeded Penetration of SW

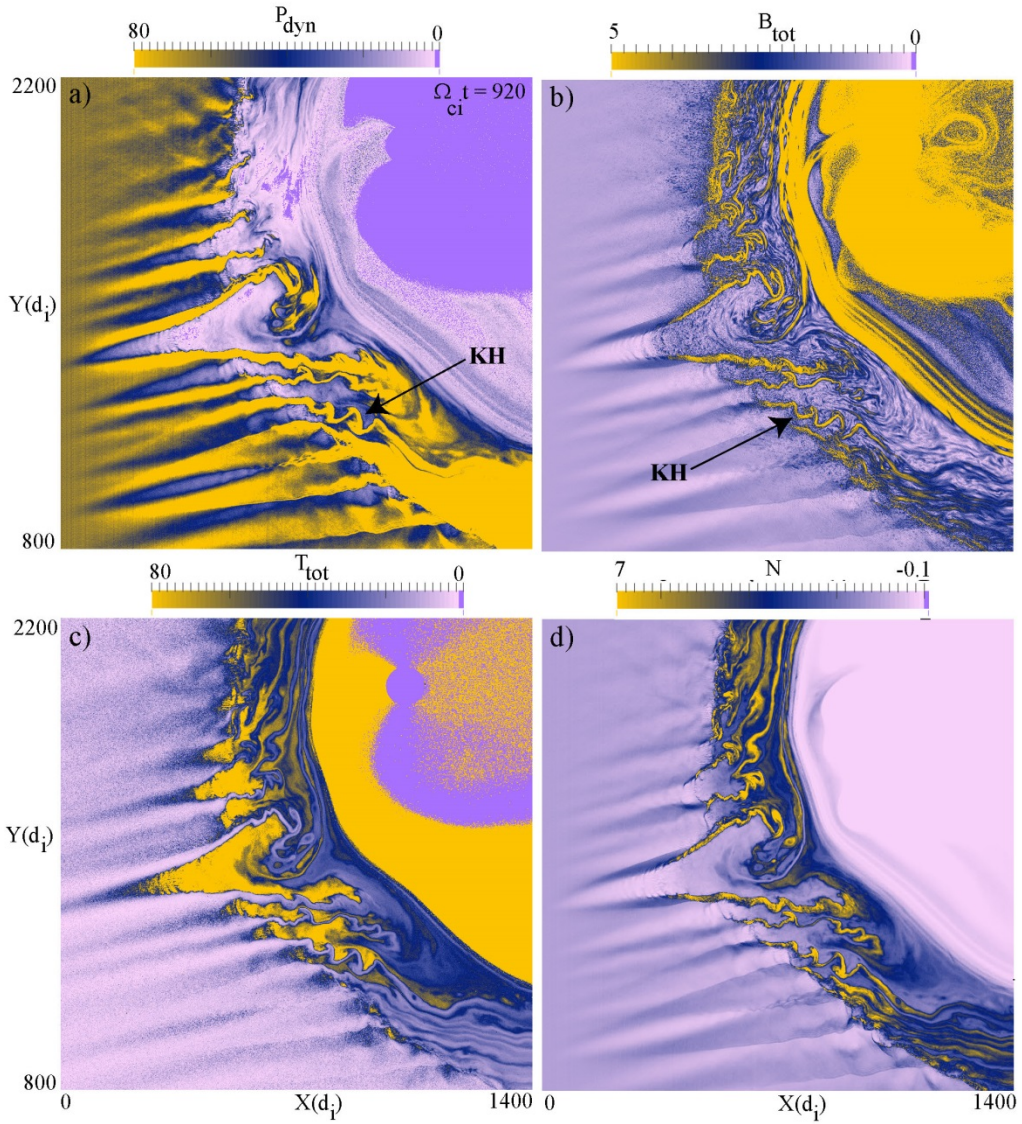




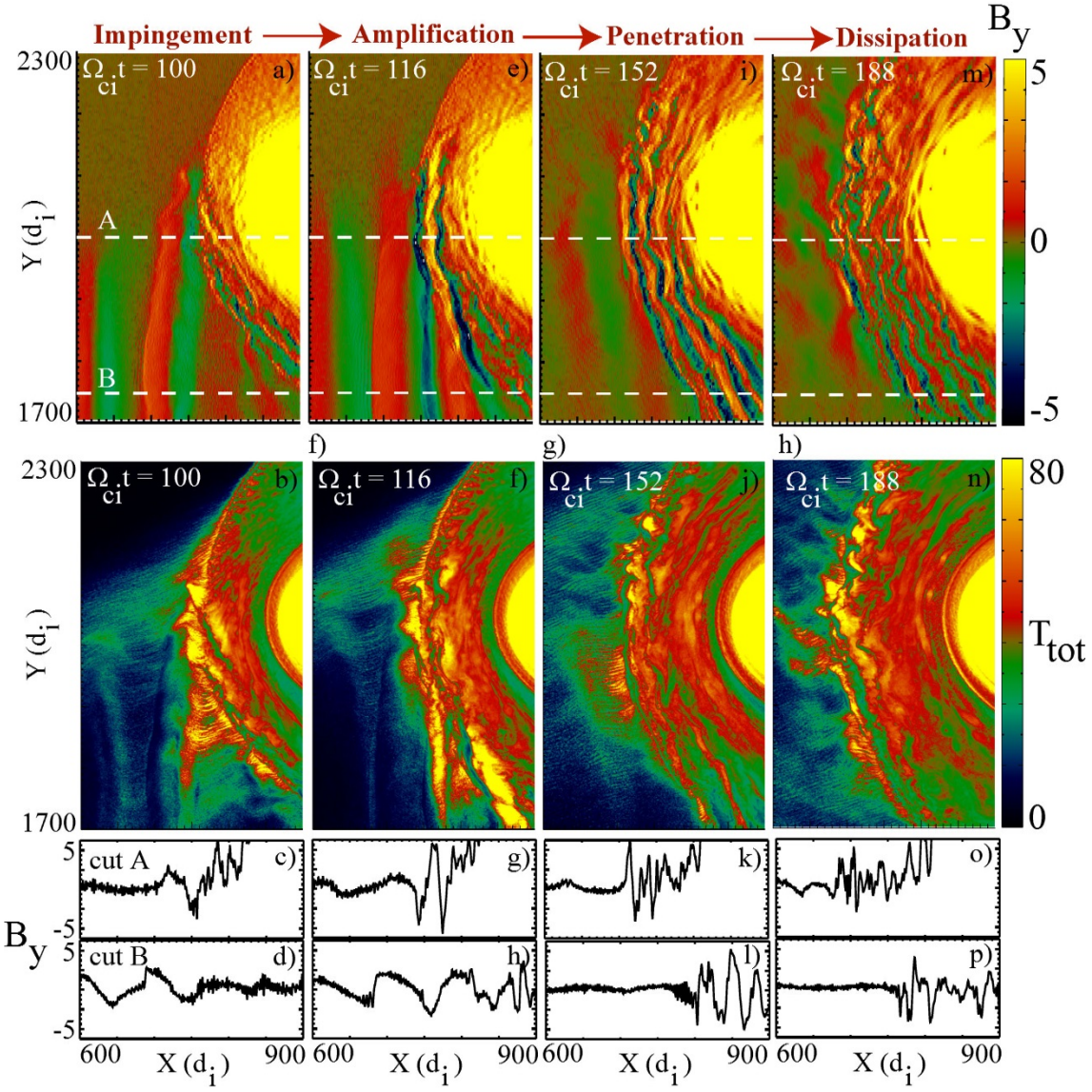
Jets Reaching the MP



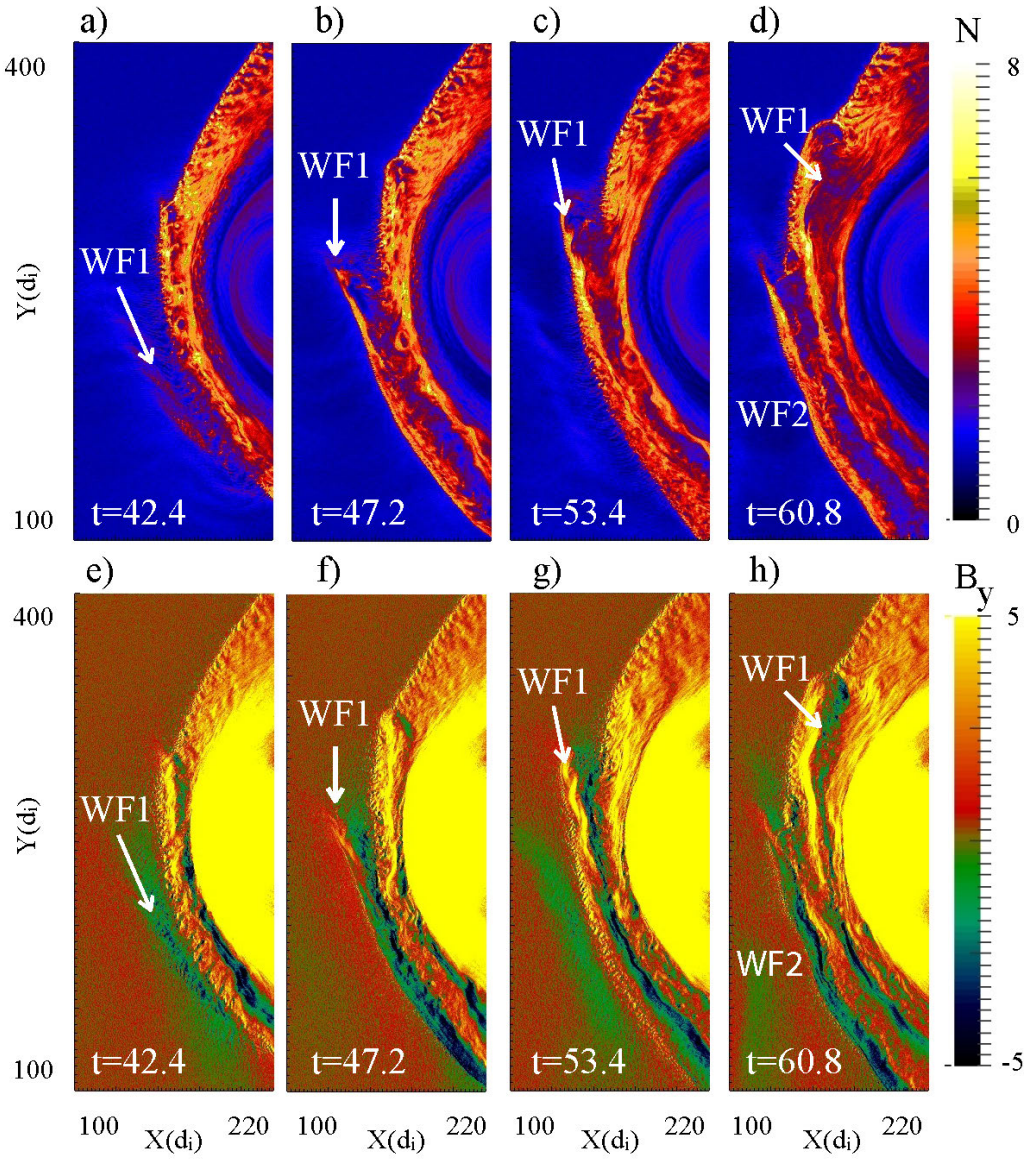
Space Weather Worthy Effects



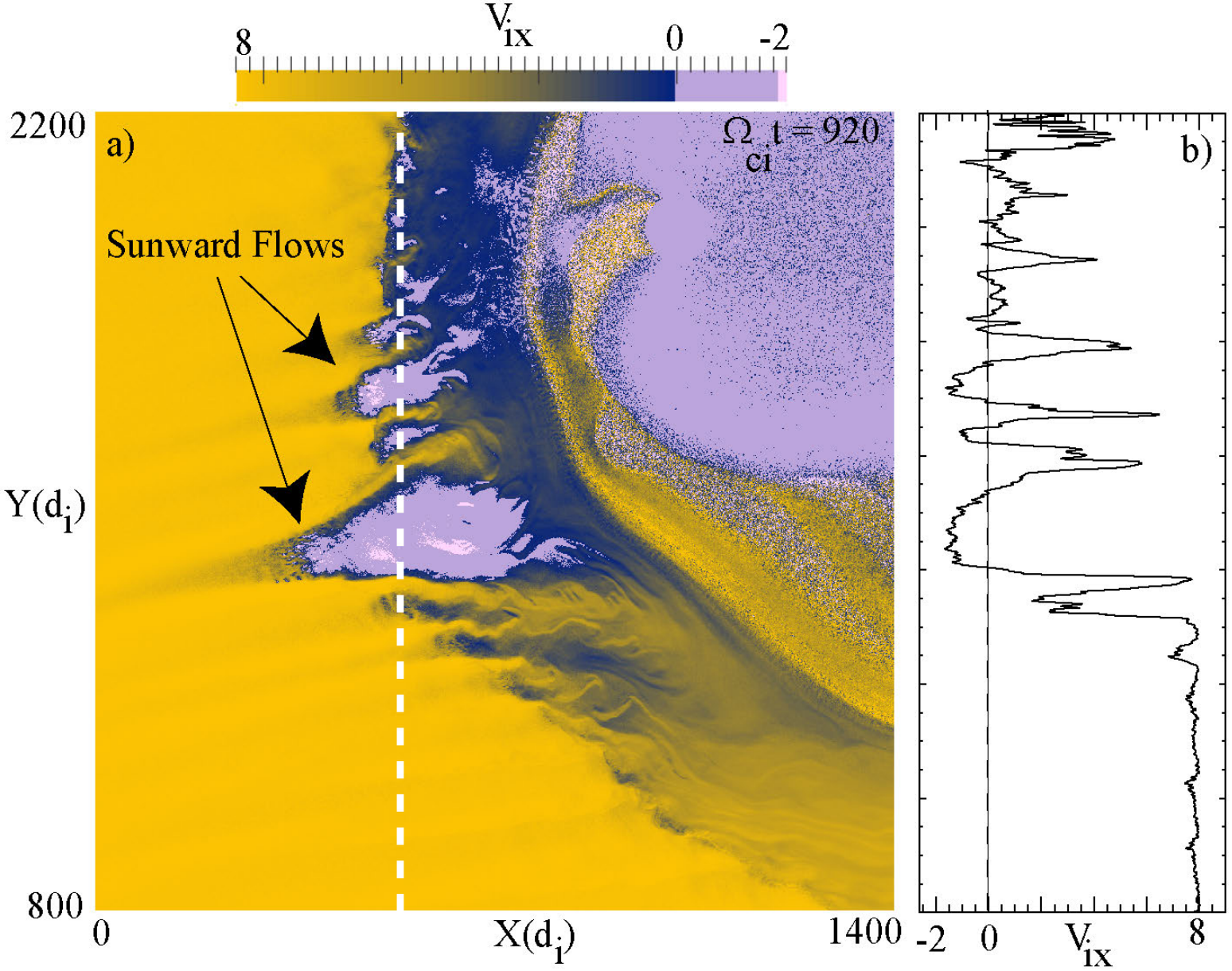
Shocklets and their Dissipation



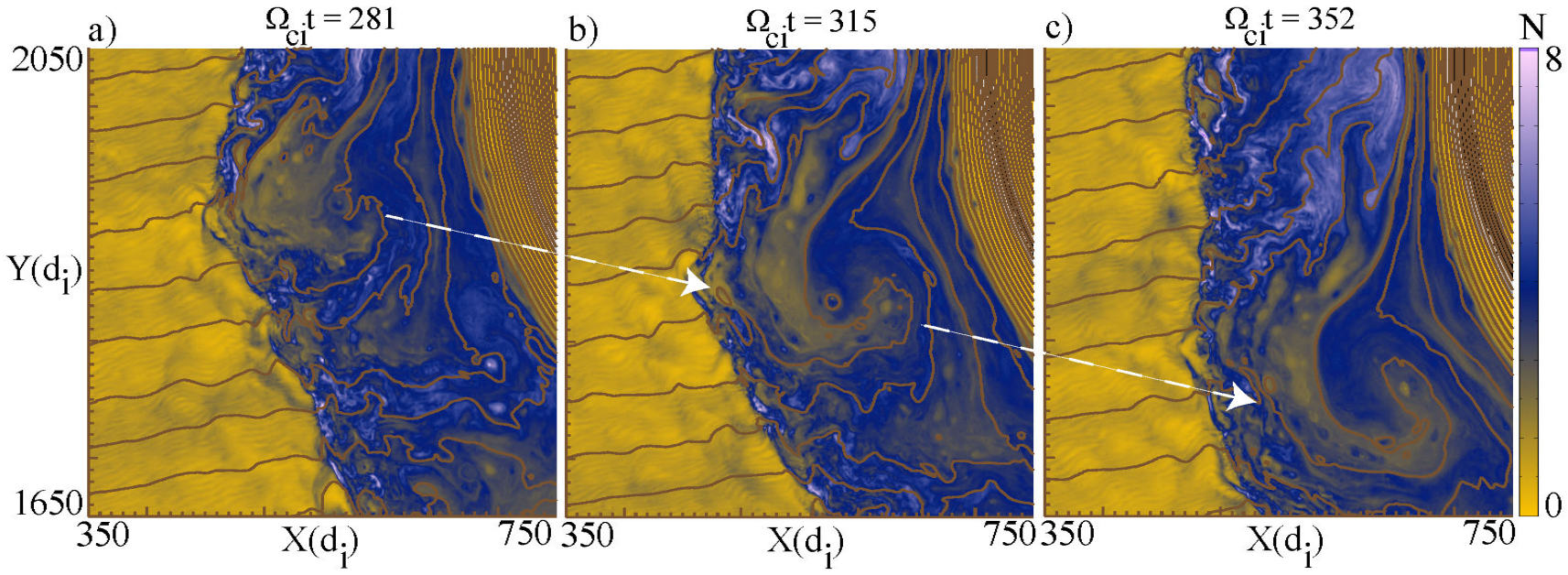
Penetration of Large Amplitude Structures



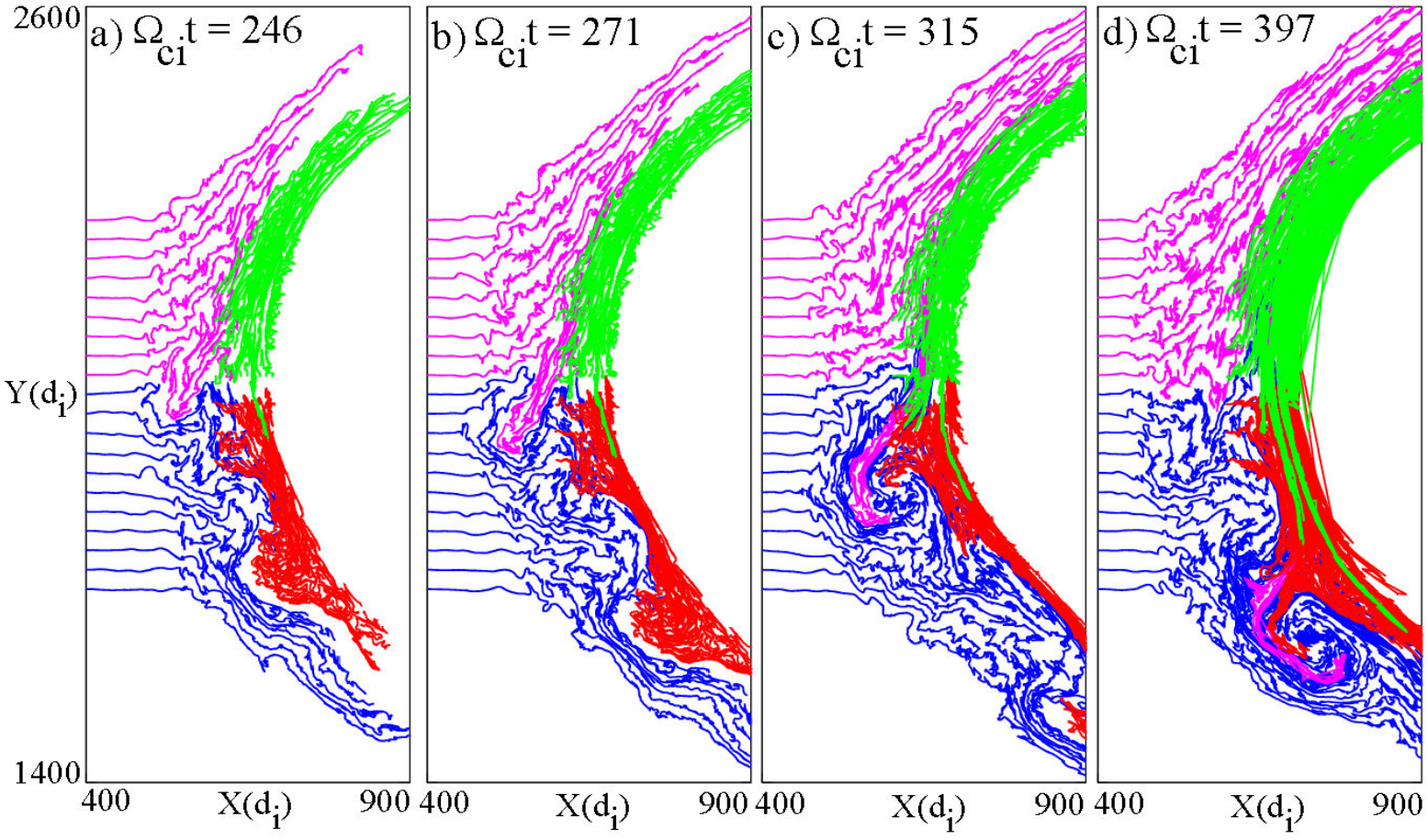
Sunward Flows!



Formation of Large Vortex Inside the Sheath!



Pathlines

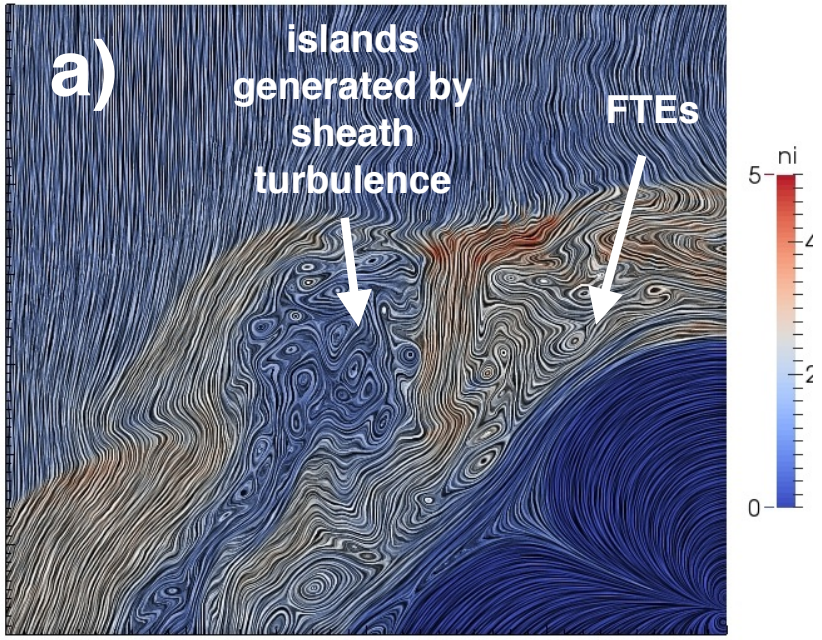

a) $\Omega_{ci}t = 246$
b) $\Omega_{ci}t = 271$
c) $\Omega_{ci}t = 315$
d) $\Omega_{ci}t = 397$
2600
1400
Y(d_i)
400
X(d_i)
900

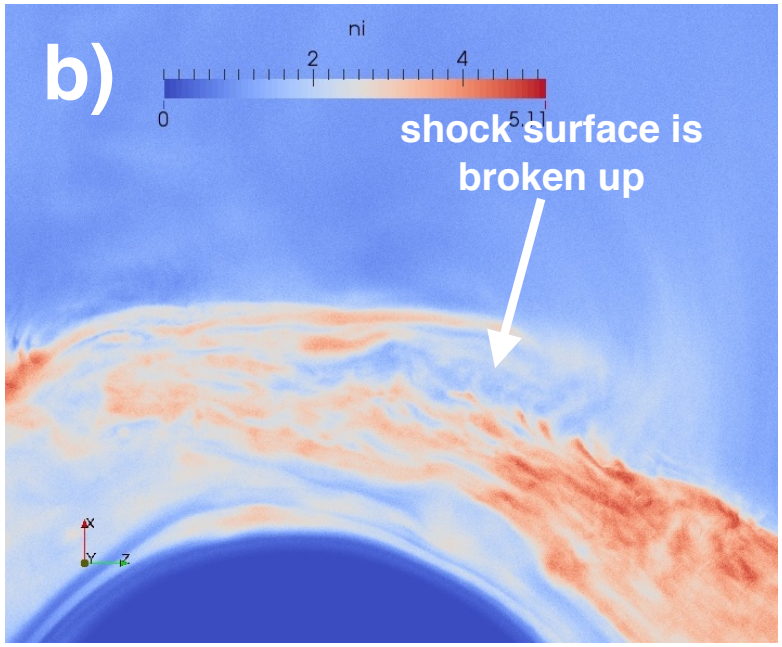
2D global full PIC

- Confirms the generation of microreconnection as observed in global hybrid

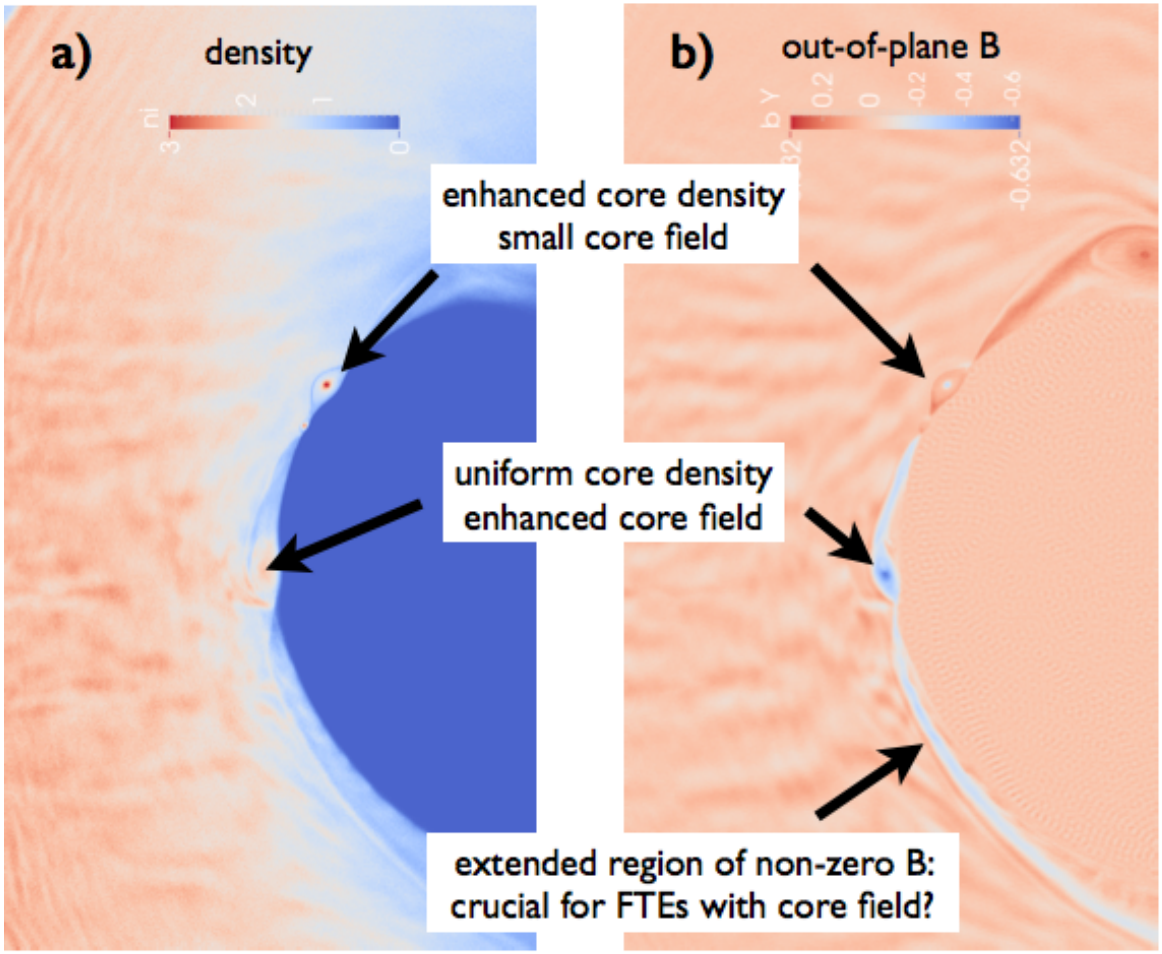
- Confirms time-dependent reconnection at the magnetopause and formation of magnetic flux ropes as seen in global hybrid

Turbulence + Microreconnection



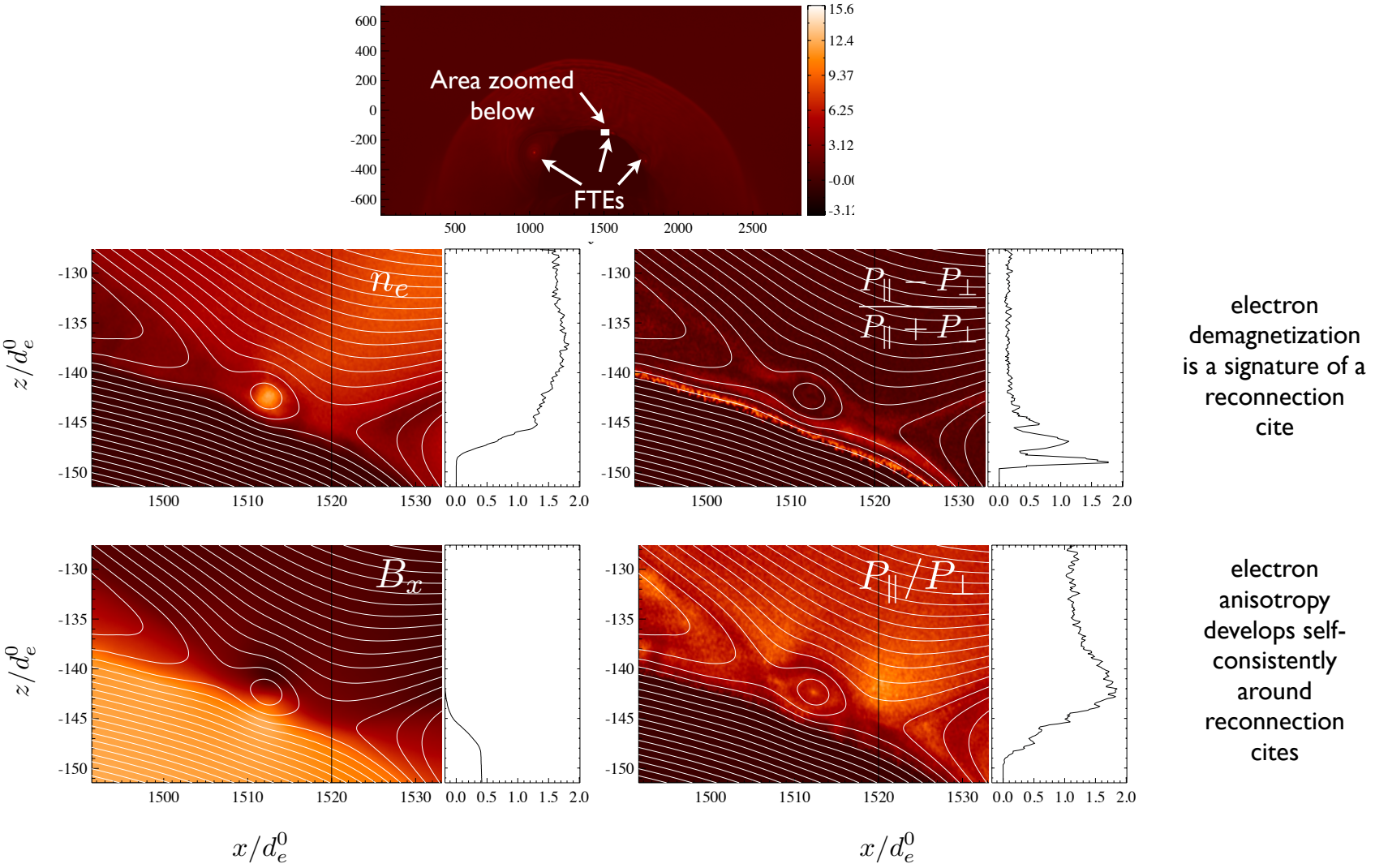


Time Dependent Reconnection



Science target: coupling between magnetic reconnection and global geometry and the influence of external driving; Findings: unsteady, multiple X-line reconnection, structure of FTEs, etc,
Applications: the Earth's magnetosphere, other planetary magnetospheres

Electron Physics



electron demagnetization is a signature of a reconnection cite

electron anisotropy develops self-consistently around reconnection cites

3D global: Hybrid vs MHD

- Major differences in the global structure of magnetosphere in hybrid vs MHD

3D

Magnetic nulls on the MP

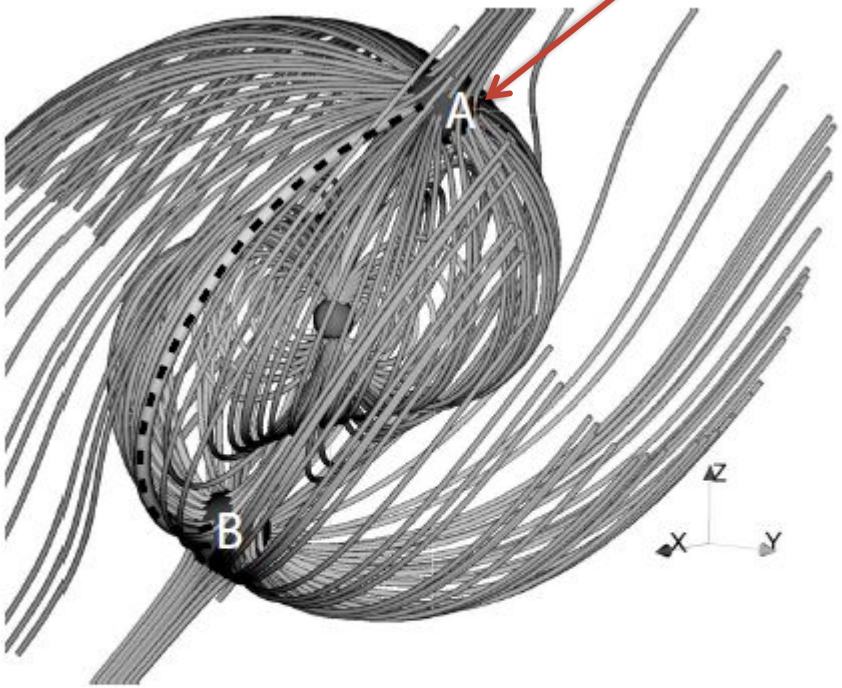


FIG. 3. This figure illustrates the three-dimensional version of Dungey's (Refs. 18 and 19) vacuum superposition model. In general (i.e., when the solar wind magnetic field is not parallel or antiparallel to Earth's dipole moment), there are two magnetic nulls (A and B) which lie on a closed magnetic field line (dashed line). This closed field line, the magnetic separator, is the three-dimensional analogue of the two-dimensional X lines of Fig. 2.

Dorelli & Bhattacharjee, 2008

MHD – Radial IMF

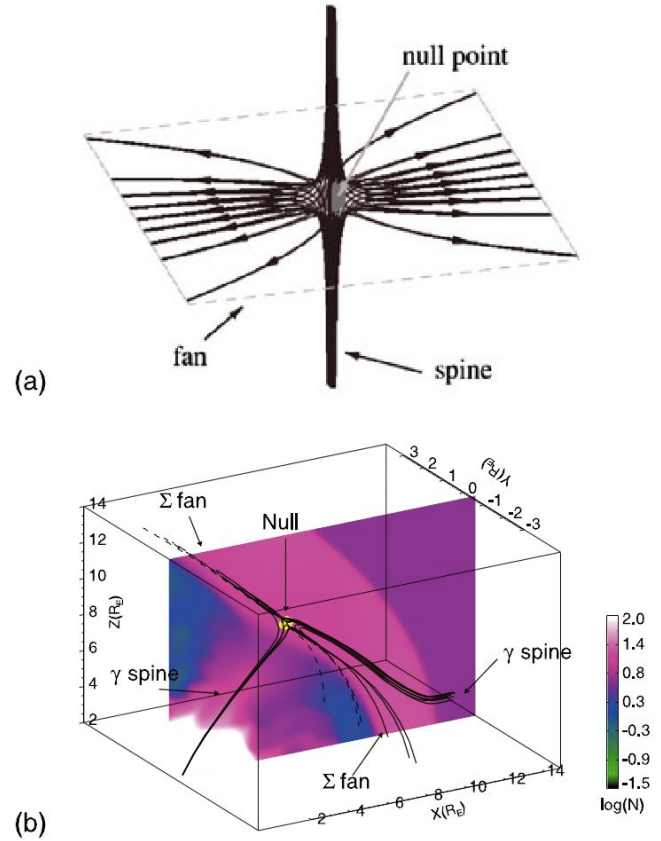


Figure 1. (a) An isolated type B null and potential magnetic field lines nearby (adapted from *Pontin* [2011]). (b) The single type A null, located at (5.71, –0.01, 9.22) R_E in the north cusp region, is marked by a yellow spot, and the around magnetic field lines under radial IMFs are also presented. Background is the contour of the logarithmic values of the plasma number density in the noon-midnight meridian plane.

Tang et al., JGR, 118, 2013

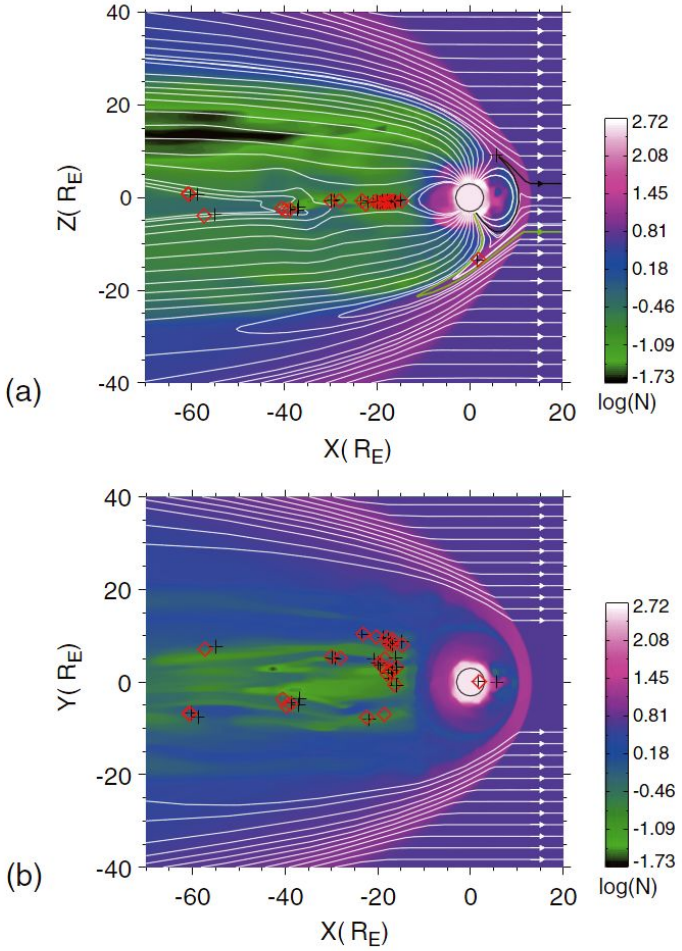


Figure 2. The projection of detected magnetic nulls in (a) the noon-midnight meridian plane and (b) the equatorial plane, where two different types of magnetic nulls are shown by the black plus signs and red diamond signs. The background contour of the logarithmic plasma number density and black magnetic field lines illustrate the basic structure of solar wind-magnetosphere system. Two newly generated open magnetic lines by north and south cusp reconnection are selected and shown in black and green color, respectively.

Note that null points are along the cusp regions

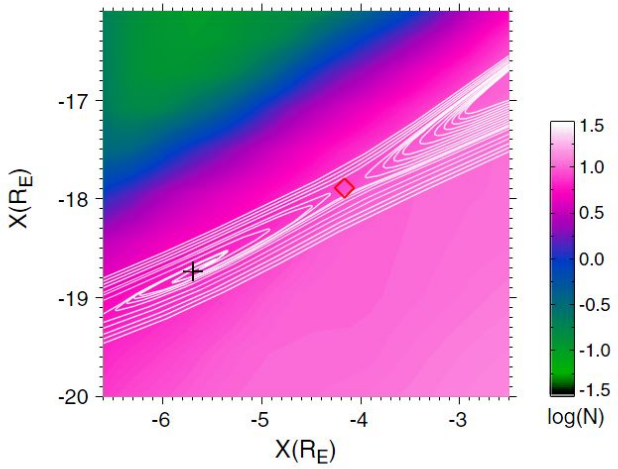
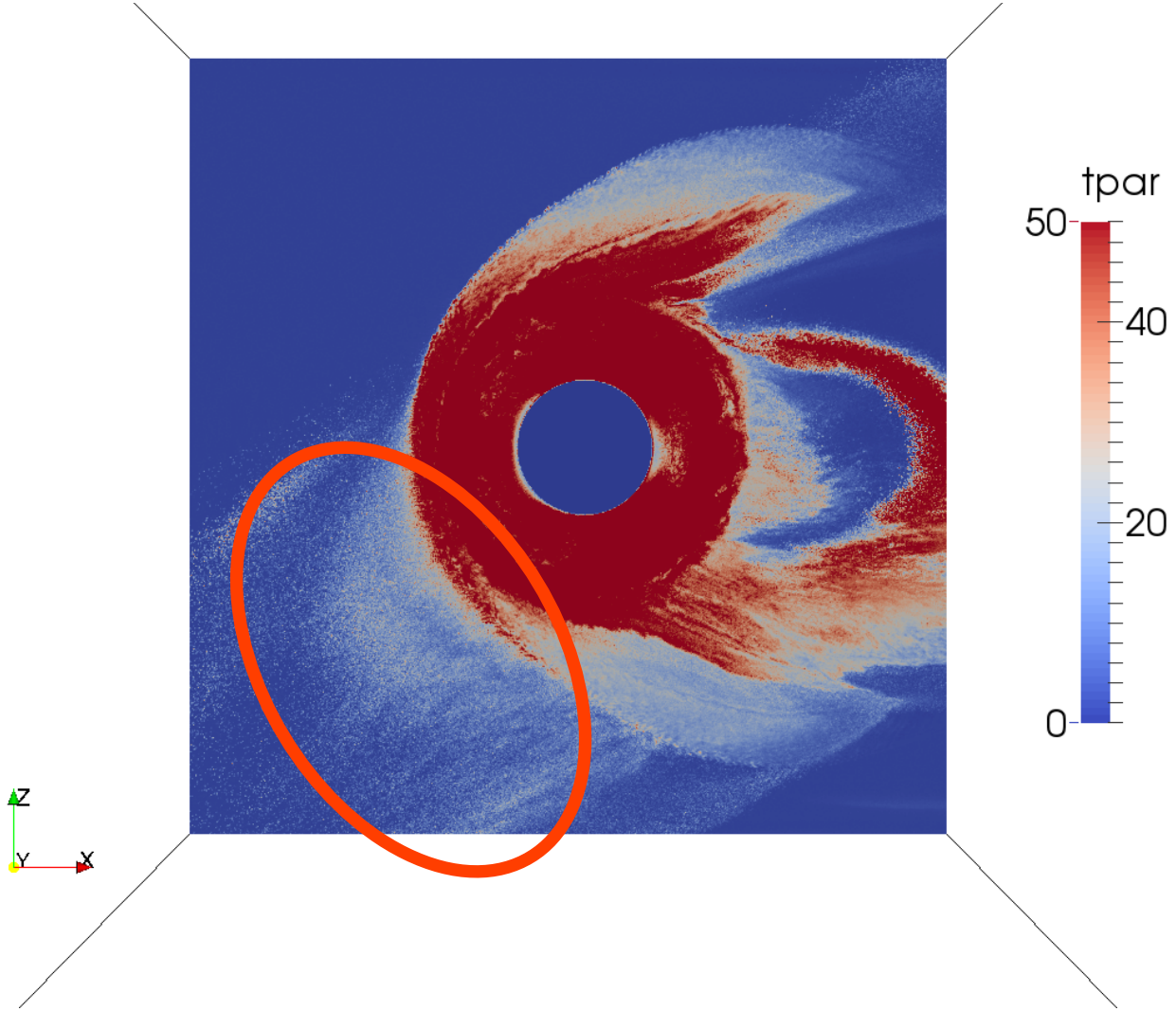
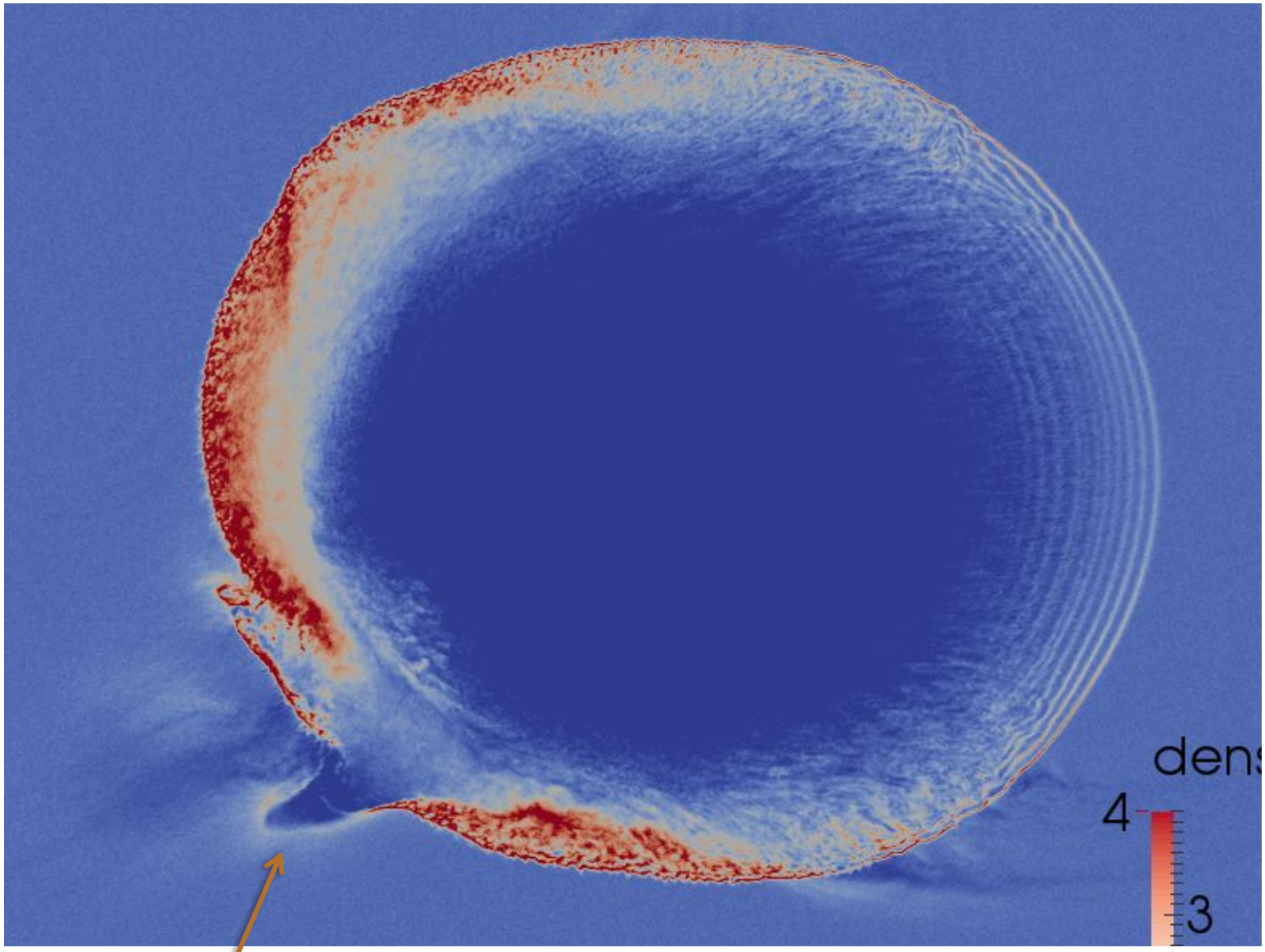


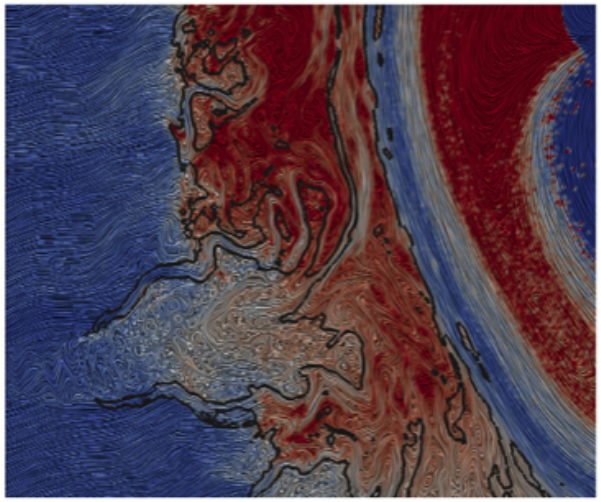
Figure 3. The local magnetic null pairs in the Southern Hemisphere. Comparing with Figure 2a, they have moved several Earth radii tailward.

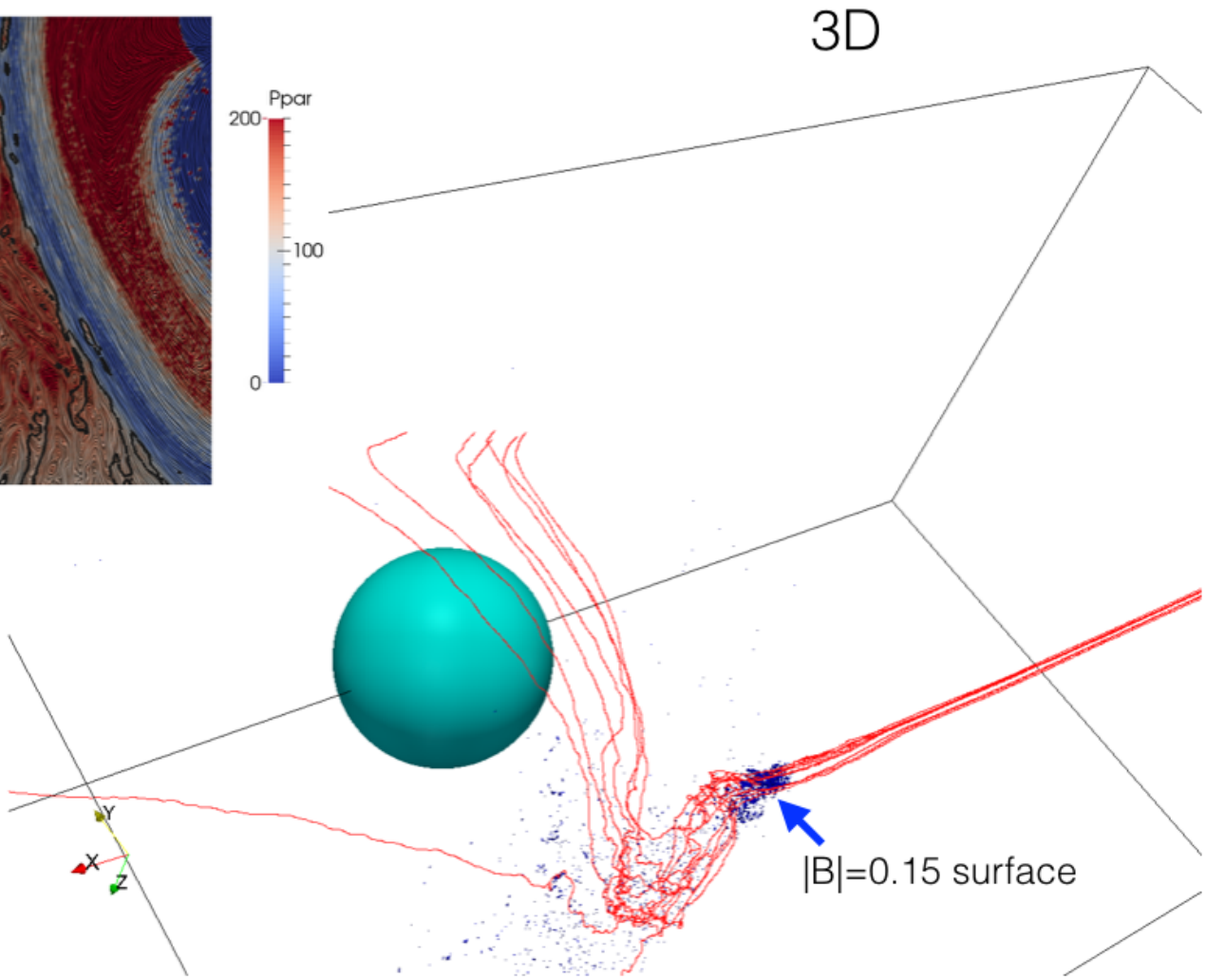
Turbulence in 3D Global hybrid Simulations



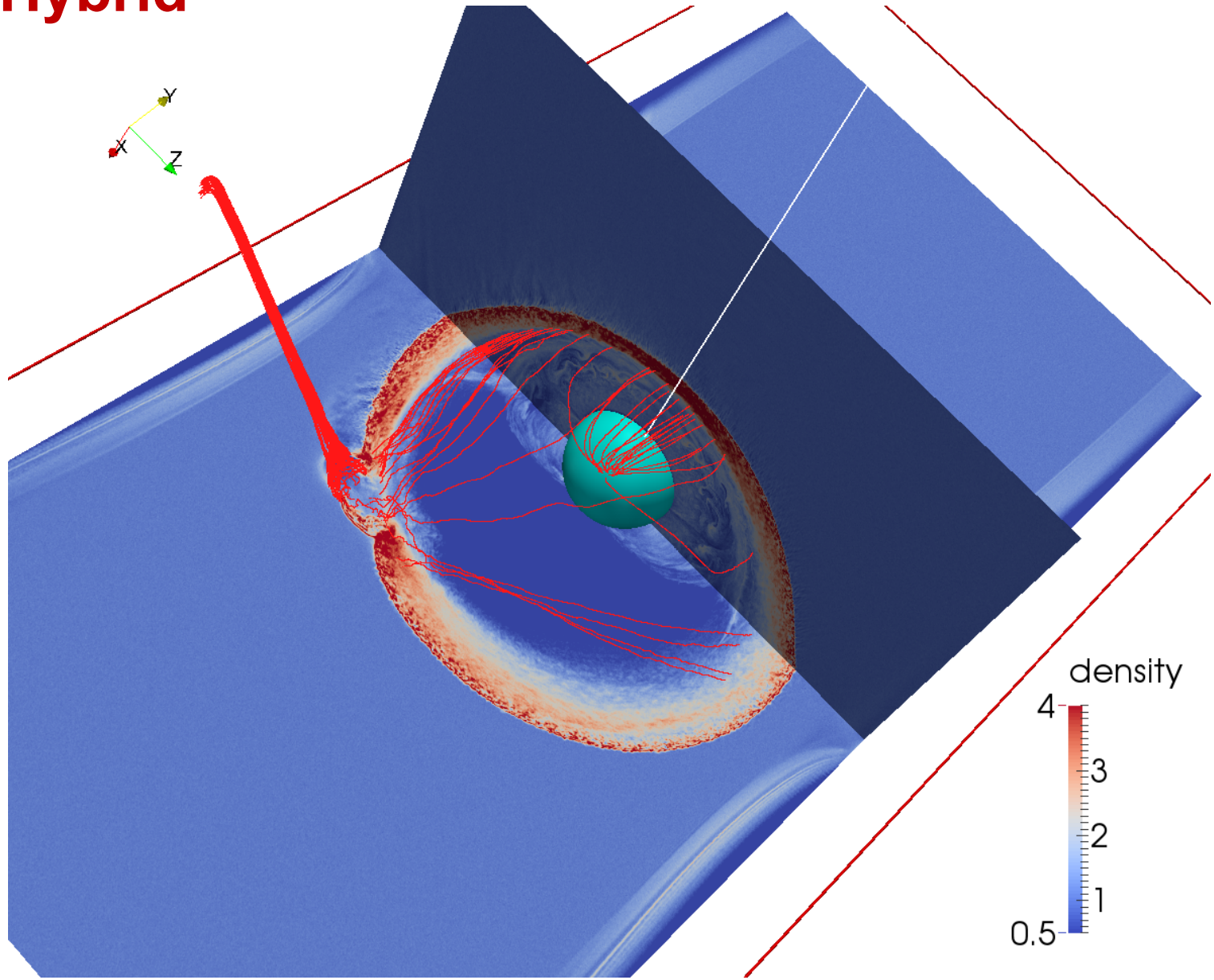

dens
4
3
caviton

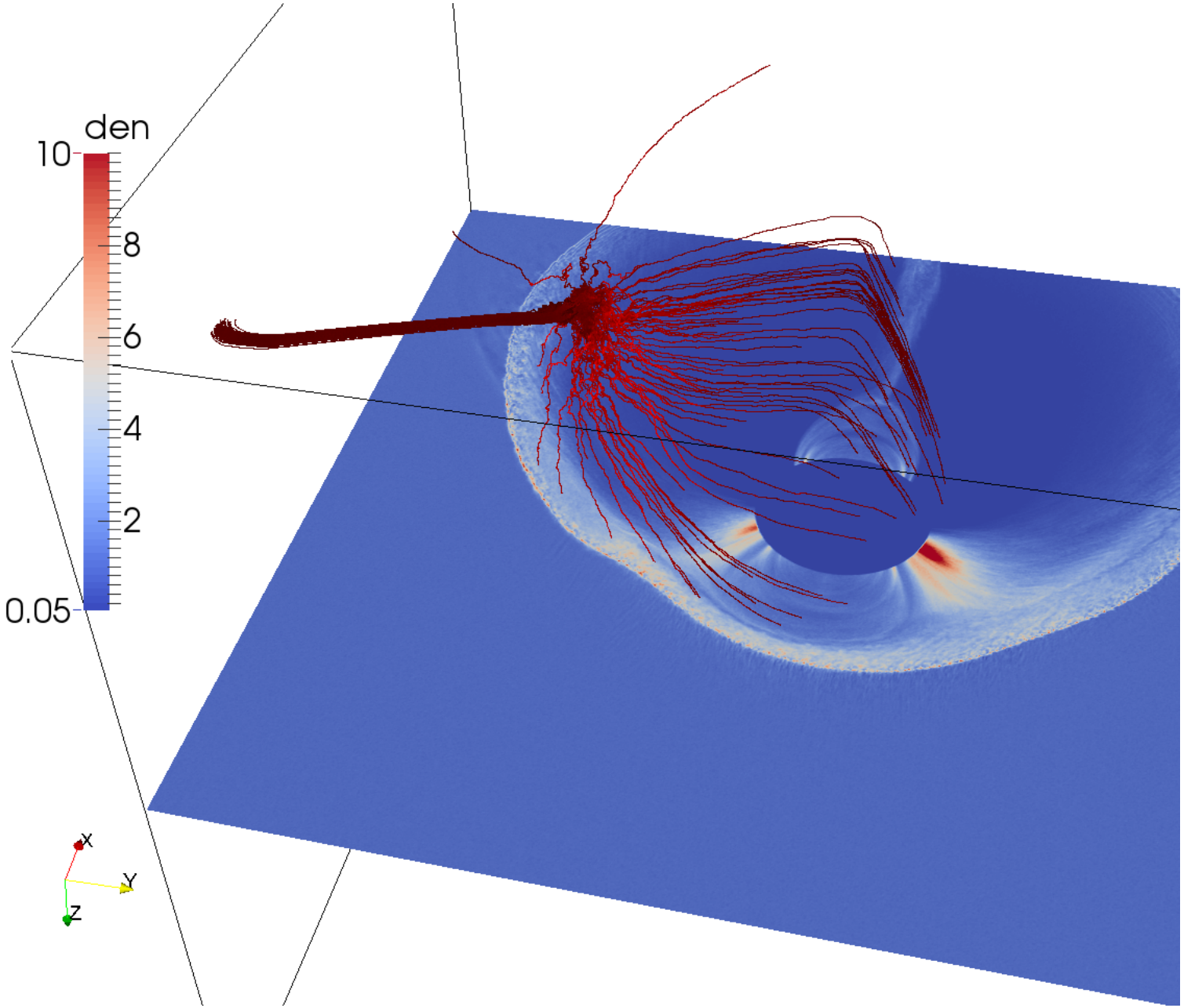
2D projection



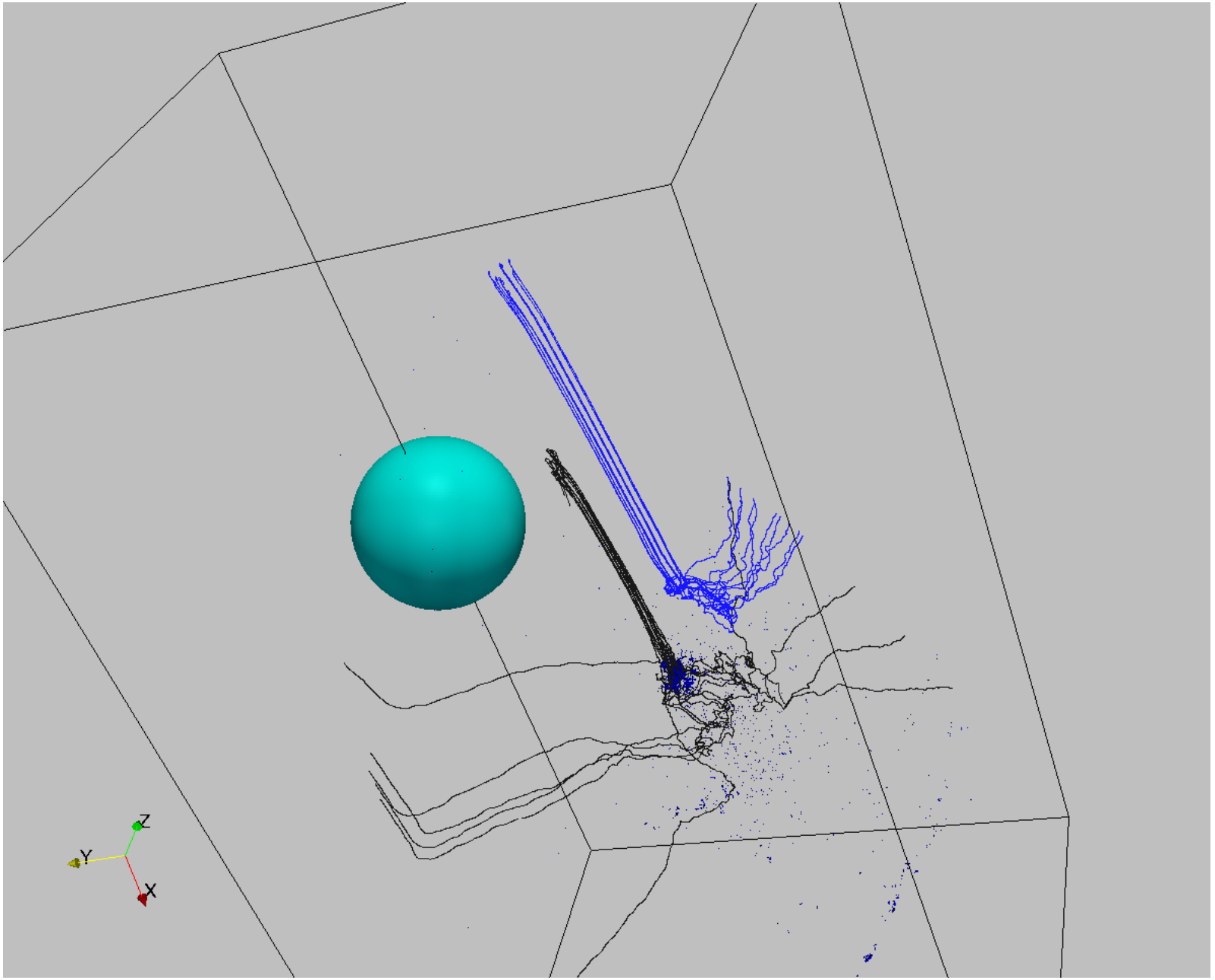


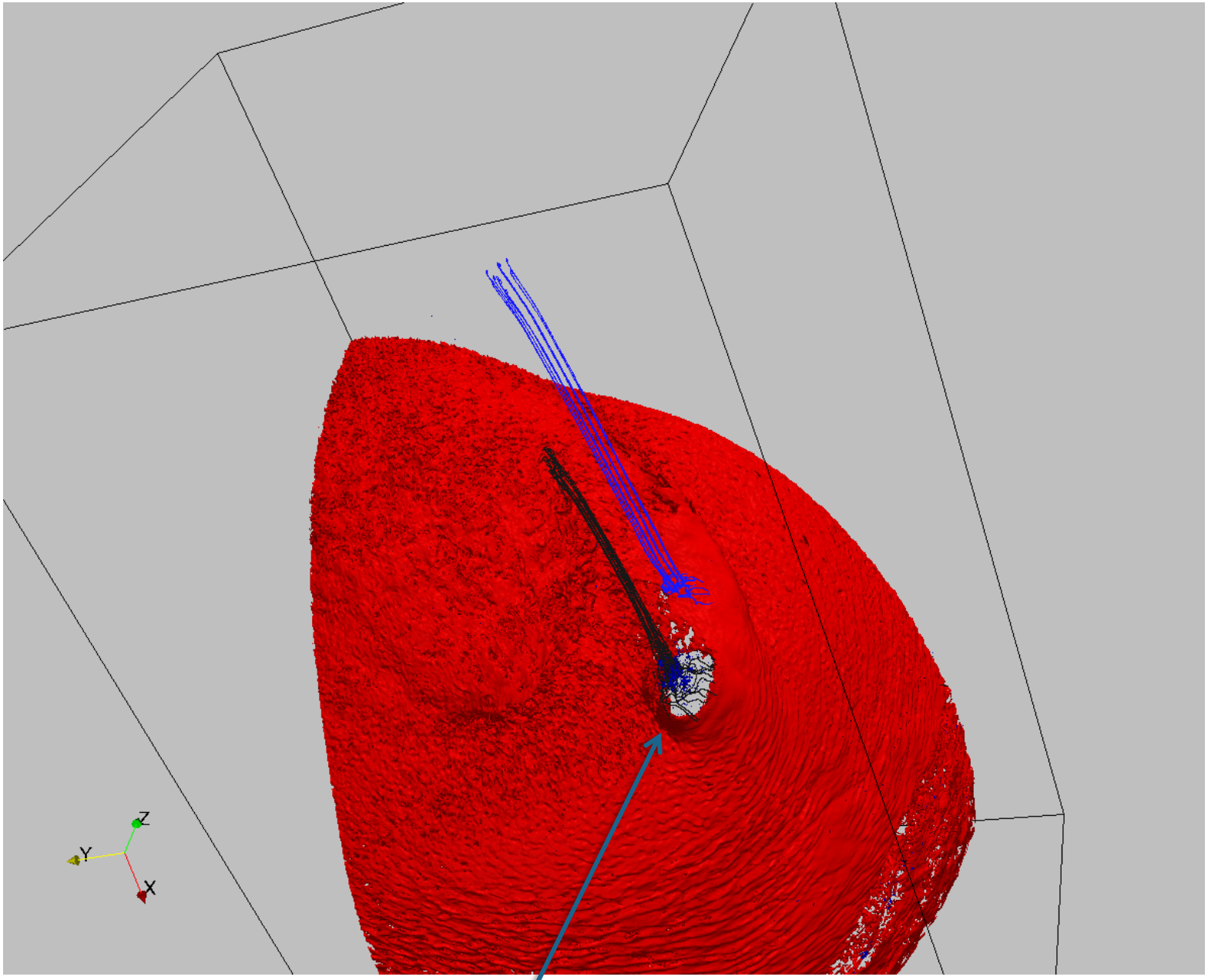
3D Hybrid



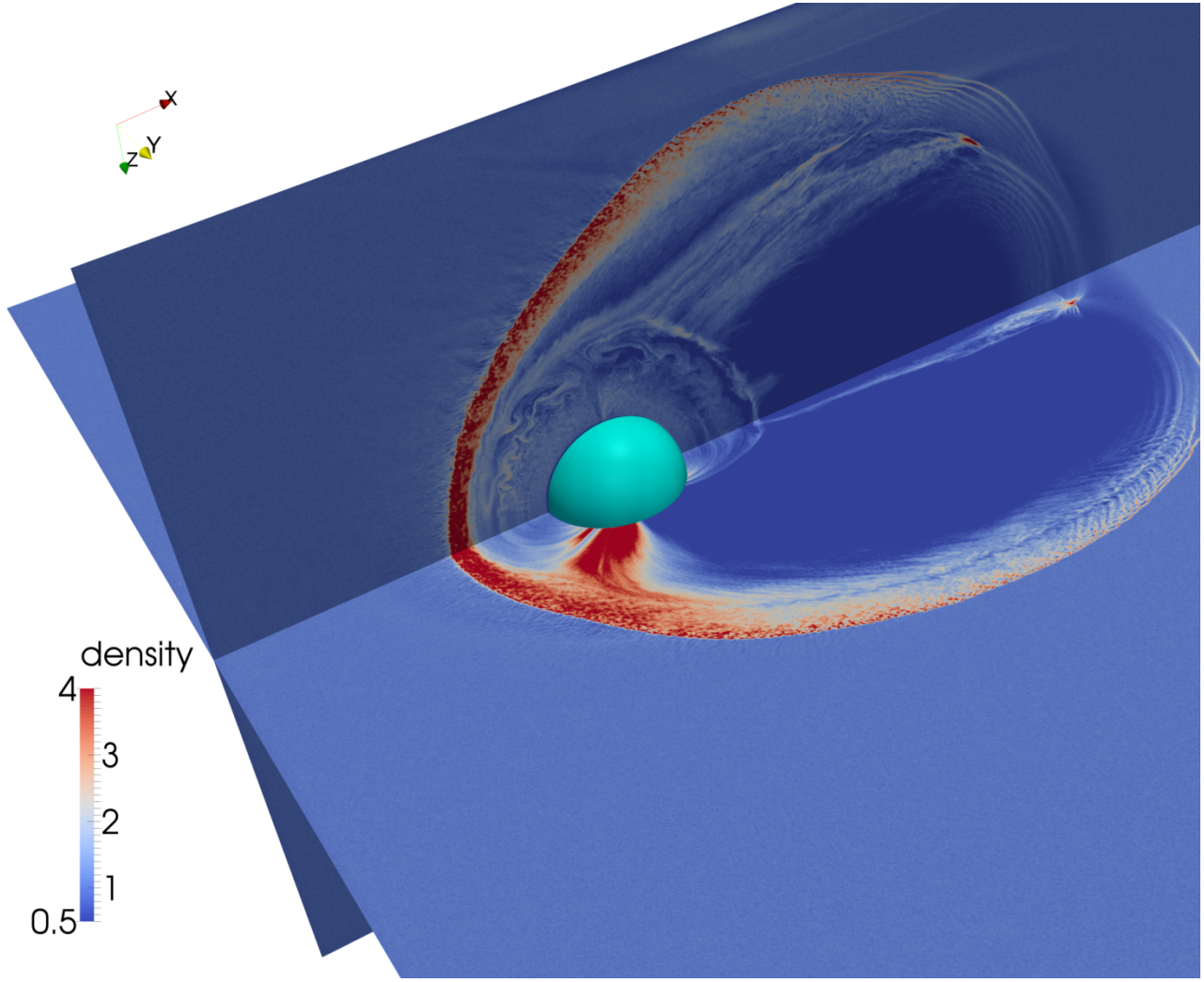

den
10
8
6
4
2
0.05
x
y
z

“fan” like feature occurs at many spots along the bow shock!

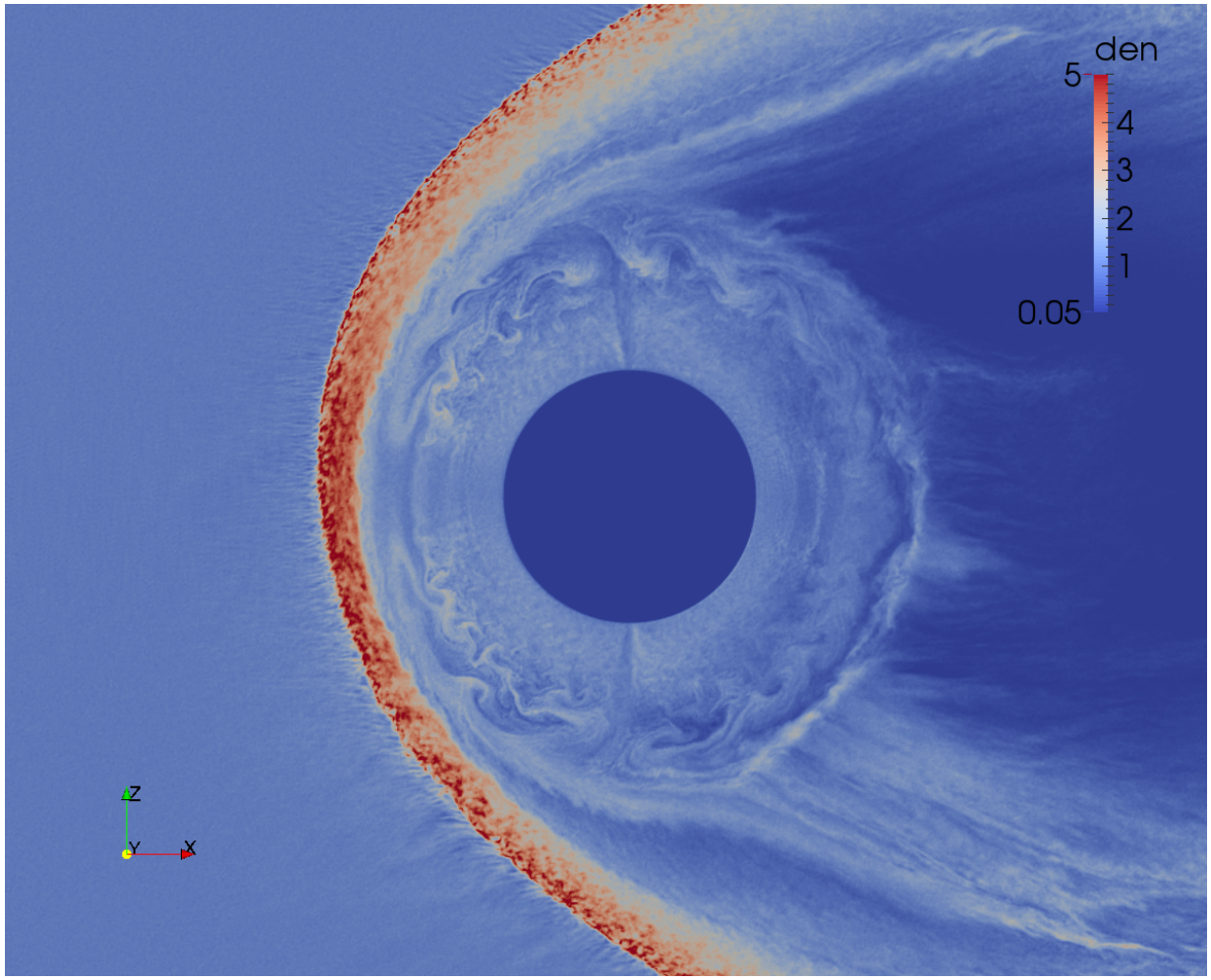



Z
Y
X
caviton

Kelvin-Helmholtz Instability



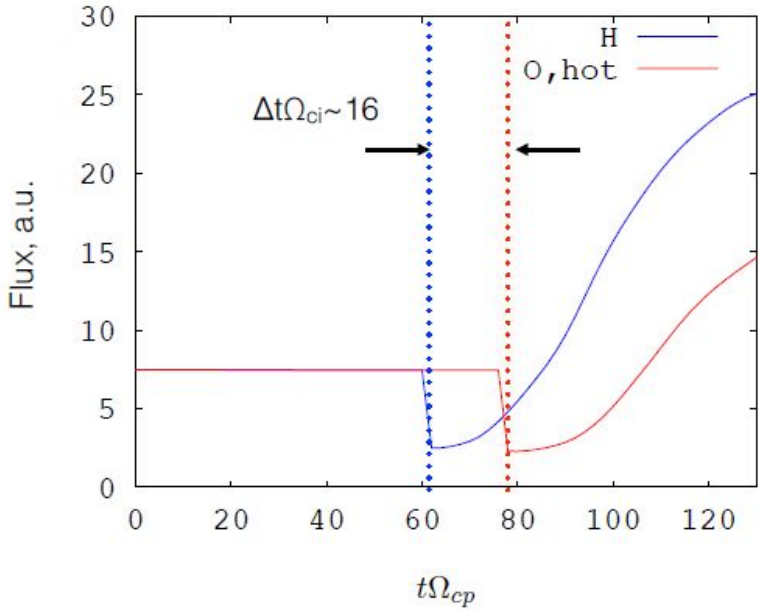
Kelvin-Helmholtz Instability



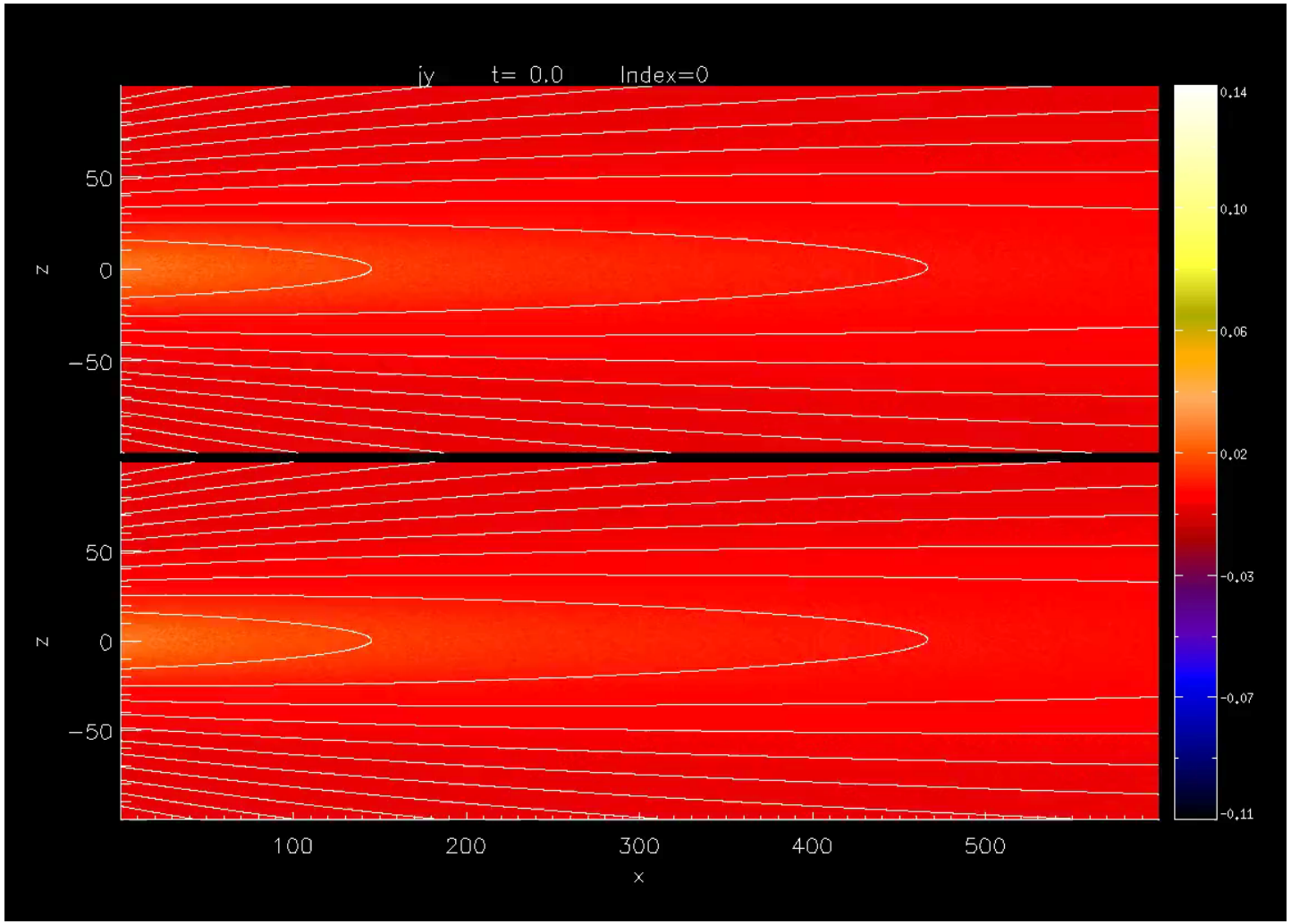
Reconnection Onset

- Electron physics important in the onset problem + details of dissipation

When oxygen is hotter than protons:
Oxygen delays the onset and reduces the unloading rate
(simply an effect of beta?)



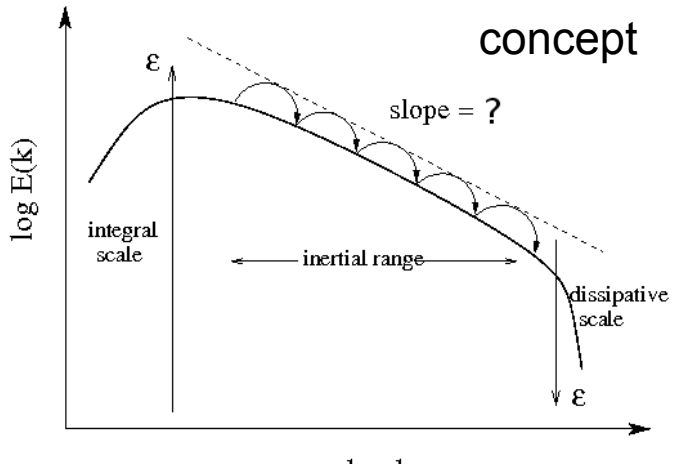
Reconnection Onset

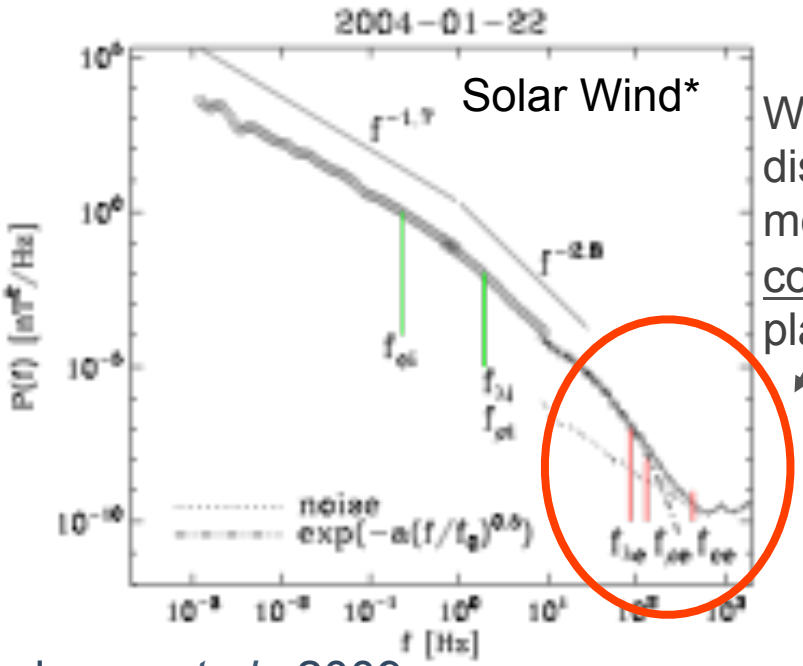


O+

Proton

Turbulence in Collisionless Plasma



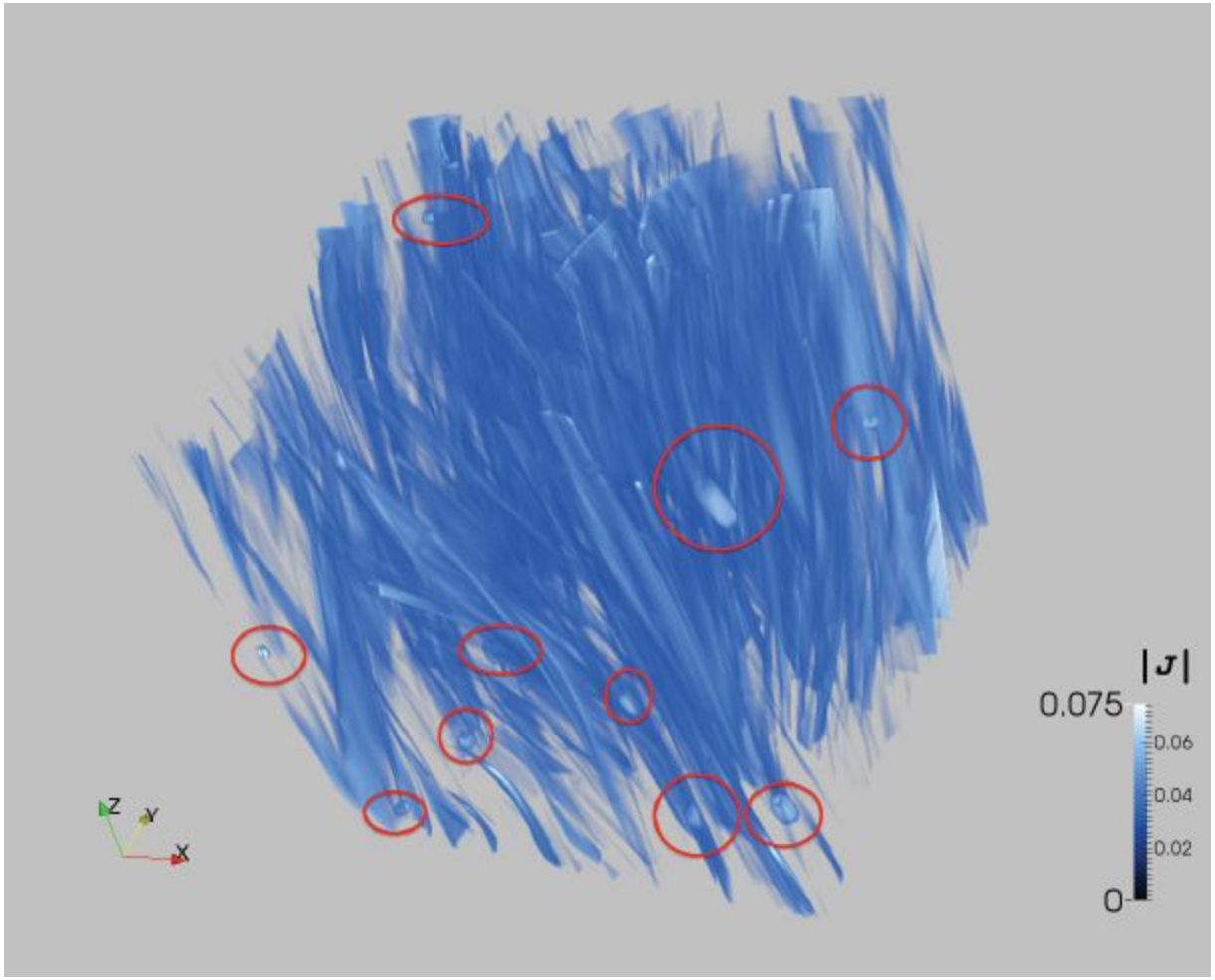


What is the dissipation mechanism in collisionless plasmas?

2D fully kinetic simulation of flow-driven turbulence

*Alexandrova, *et al.*, 2009

3D Full PIC Simulation of Cascading Turbulence



Conclusion

- Electron physics is important in questions related to partitioning of energy, dissipation, and onset

- Ion physics plays a key role in the generation of turbulence on the dayside + formation of ring currents, effects of O+, among others

- Kinetic effects are important in space weather studies